Reclaimed water irrigation water quality impact assessment

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Introduction

In an effort to reduce demand on municipal potable water supply, the City of Austin is increasing utilization of reclaimed water. Although the benefits to potable water supply resources are clearly realized, the reclaimed water contains pollutants which may have the potential to degrade adjacent creeks and springs in some situations. For example, reclaimed water has elevated concentrations of nutrients (such as nitrogen and phosphorus) that may be an order of magnitude higher than stormwater runoff from developed urban land and two orders of magnitude higher relative to ambient surface water condition (Figure 1).

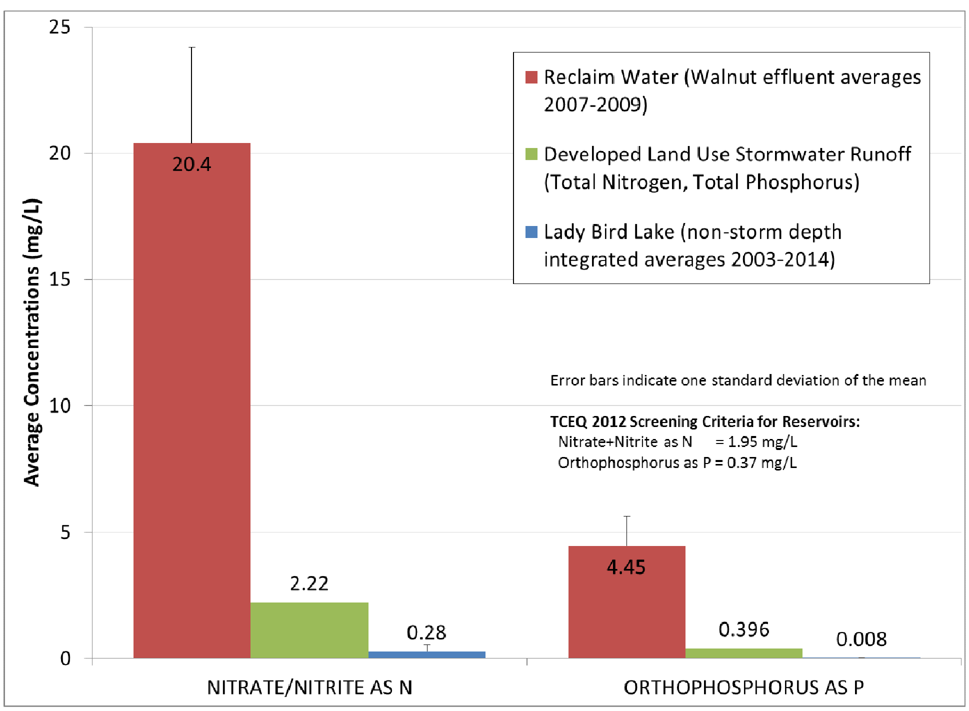

Figure 1: Nutrient concentrations of reclaimed water relative to developed land stormwater runoff and Lady Bird Lake averages (2003-2014). Nutrient concentrations in reclaimed water may be two to three orders of magnitude higher than ambient surface water.

Eutrophication is a well-described process which results when a water body receives an excessive supply of nutrients. In aquatic systems, nutrients such as nitrogen (N) and phosphorus (P) support the growth of algae and aquatic plants. An overabundance of nitrogen and phosphorus can alter the growth habits of algae by increasing to a rate that is faster than the ecosystem can manage. This nutrient enrichment can cause an increase in algal biomass (Figure 2) to the extent that entire reaches of streams show aesthetic degradation (Wharfe et al. 1984, Biggs 1985, Biggs and Price 1987, Welsh et al. 1988), loss of pollution-sensitive invertebrate taxa (Quinn and Hickey 1990), clogging of water intake structures (Biggs 1985), and degradation of dissolved oxygen and pH levels in the water column (Quinn and Gilliland 1989).

Figure 2. Examples of increased algal biomass in which filamentous algae covers the surface water at two sites within the project area; Site 10882 on Tannehill branch near Morris Williams golf course (left) and Site 10778 on Williamson Creek near Roy Kizer golf course (right).

Eutrophication of surface water resulting from land application of treated wastewater has been previously documented in the Austin area. The land application of treated wastewater was identified as a probable source of elevated nitrogen and phosphorus and cause of periphytic algal blooms in upper Bear Creek (Turner 2010). In addition, a strong biogenic nitrogen isotope signature is observed in a spring down-gradient from a golf course utilizing wastewater effluent for irrigation (COA unpublished data) and analysis of stormwater runoff data indicated higher concentrations of nutrients in runoff from golf courses irrigated with wastewater effluent versus golf courses without effluent irrigation (King et al. 2007, COA 2005). U.S. Geological Survey investigations in Florida have previously identified increases in chloride and nitrate in groundwater wells beneath municipal wastewater effluent sprayfields (Pruitt et al. 1988), and land application of treated municipal wastewater effluent was identified as a major source of nitrate to the regional discharge point of the Upper Floridan Aquifer (Katz et al. 2009).

Instream algal biomass can be difficult quantify, and chlorophyll *a* is commonly used as a surrogate to determine the algal biomass of a system. The Texas Commission on Environmental Quality (TCEQ) (2006) showed that benthic (attached) algal chlorophyll *a* could be a better indicator of nutrient enrichment than water-column chlorophyll *a* in small, fast flowing Texas streams. The organic growth of algae, cyanobacteria and heterotrophic microbes attached to the benthic surface is periphyton. The periphyton that colonize the surfaces of submerged rocks and other stable substrate can easily be scraped from the surface with standard methods in order to collect reproducible and standardized samples from streams.

In addition to the chlorophyll *a* concentrations of the periphyton, the carbon to nitrogen to phosphorus (C:N:P) stoichiometry in algal cells has been shown to respond to increases in nutrient loads. An increased load of nitrogen or phosphorus leads to lower carbon to nitrogen or carbon to phosphorus ratios in stream and lake periphyton communities (Hillebrand and Kahlert 2001, Hillebrand and Kahlert 2002, Stelzer and Lamberti 2001, Frost and Elser 2002, Bowman et al. 2005). The increased amounts of nitrogen or phosphorus in the algal cells can lead to an increase in the algal growth rates (Rhee 1973, Droop 1974). This may allow benthic algal biomass to increase more rapidly in nutrient enriched water or contribute to nutrient spiraling downstream by increasing nutrients available to downstream reaches.

In the context of potential stream nutrient enrichment, the concerns related to the application of reclaimed water in close proximity of creeks include:

- migration of the reclaimed water to the creeks and shallow groundwater through infiltration and lateral groundwater flow;
- direct irrigation into creeks during improper spray application; and/or
- excessive constituent loading into riparian soils that exceed natural assimilative capacities and consequent transportation to creeks during runoff events.

To enable evaluation of the potential impacts to surface and groundwater quality, City of Austin Watershed Protection Department staff collected water samples from creeks and springs adjacent to locations with reclaimed water irrigation occurring within the Critical Water Quality Zone (CWQZ) and/or floodplain as defined by the City of Austin Land Development Code. This project was conducted in two phases.

Phase 1 sampling was a one-time sample effort of upstream and downstream conditions relative to on-site reclaimed water and local spring discharge in October of 2014. The results of Phase 1 sampling (Clamann et al. 2015) illuminated spatial and temporal variability and allowed application of robust statistical analysis methods which enabled the determination of the sampling locations and frequencies for Phase 2.

Phase 2 sampling included four sample events during the summer of 2015. The following is a summary of the combined results of the Phase 1 and Phase 2 sampling from on-site reclaimed water, surface water, groundwater and periphyton. The results of the Phase 2 sampling supported many of the preliminary Phase 1 conclusions.

Methods

Field Methods

The field investigation for Phase 1 was conducted on October 15, 2014. Phase 2 field investigations were conducted on July 23, August 27, September 24, and October 20 of 2015. Physiochemical parameters were collected in the field using a Hydrolab multiprobe water quality sonde. Spring and stream discharge was measured with a Marsh-McBirney Flowmate. Water samples from reclaimed water sources (irrigation lines and ponds), surface water (creeks), groundwater (spring discharge) and periphyton (from rock scrapings) were collected by WPD staff, preserved in ice, and delivered to the Lower Colorado River Authority laboratory for analysis following City of Austin standard operating procedures (WRE SOP 2013).

Phase 1 of this study included 21 sites which were located within one park and three golf courses that receive application of reclaimed water (Table 1 and Figure 3). Sites included four known springs (10765, 661, 662, and 10769), on-site reclaimed water irrigation source ponds or supply lines (10767, 10775, 10779, and 10768), and upstream/downstream sample sites on creeks (3858/10767, 10773/625, 3879/10778, 10770/10772, and 843/10771). The Phase 2 of this study included 15 sites within one park and two golf courses (Table 1 and Figure 3). In addition to the samples collected at the sites listed in Table 1, each event included one field replicate sample to document potential for variance within a site.

Table 1: Site list and sample schedule

Location	Site number and name	Purpose	Phase 1	Phase 2			
			Oct 2014	Jul 2015	Aug 2015	Sep 2015	Oct 2015
Bartholomew Park	3858 Tannehill Creek @ Berkman Dr	upstream of irrigation	✓	x	✓	✓	no flow
	10766 Tannehill downstream Bartholomew Spring	downstream of irrigation	✓	x	✓	✓	✓
	10767 Bartholomew Park Irrigation water	source water for irrigation	✓	x	✓	✓	✓
	10765 Bartholomew Spring	groundwater spring	✓				
Hancock Golf Course	10773 Waller Creek @ 45th	upstream of irrigation	✓				
	625 Waller Creek @ 38th	downstream of irrigation	✓				
	10775 Hancock Irrigation Water	source water for irrigation	✓				
Morris Williams Golf Course	843 Tannehill @ Lovell	upstream of irrigation	✓	✓	✓	✓	✓
	10771 Tannehill @ MLK	downstream of irrigation	✓	✓	✓	✓	✓
	10770 Morris Williams Central Trib upstream	upstream of irrigation	✓	✓	✓	✓	✓
	10772 Morris Williams Central Trib downstream	downstream of irrigation	✓	✓	✓	✓	✓
	10768 Morris Williams Irrigation Pond	source water for irrigation	✓	✓	✓	✓	✓
	10769 Moose Lodge Spring	groundwater spring	✓				
	10882 Tannehill 340ft downstream of Lovell	Downstream of seep			✓	✓	✓
Roy Kizer Golf Course	10776 Williamson downstream Pleasant Valley	upstream of irrigation	Dry	✓	Dry	Dry	Dry
	3879 Williamson Creek at Dove Springs Park	upstream of spring	✓	✓	✓	✓	Dry
	661 Roy Kizer Spring	groundwater spring	✓	✓	✓	✓	✓
	10778 Williamson downstream Roy Kizer Spring	downstream of spring	✓	✓	✓	✓	Dry
	10779 Roy Kizer Reclaim Water Pond	source water for irrigation	✓	✓	✓	✓	✓
	10883 Roy Kizer Reclaimed Water Pipe	source water for irrigation		✓	✓	✓	✓
	65 Onion Creek at William Cannon	upstream of irrigation	✓				
	253 Onion Creek at McKinney Falls upper pool	downstream of irrigation	✓				
	662 Driving Range Spring	groundwater spring	✓				

shaded = sample collected, unshaded = sample not collected
"Dry" = site did not have baseflow,
"no flow" = site was sampled for periphyton, but not water chemistry due to lack of baseflow
"x" = site not sampled because facility damage; no irrigation for previous month due to repairs.
blank = site was not part of the QAPP at the time of sampling

Figure 3: Sample locations at City of Austin parks and golf courses selected to determine potential for impacts to surface and spring water for the Phase 1 and Phase 2 sample events.

Not all sites from Phase 1 were sampled during the Phase 2 field efforts. Sites that were dropped following the Phase 1 sample events include:

- Hancock golf course sites were dropped from the Phase 2 study because the Phase 1 results indicated that the surface water upstream (Waller Creek) of the site was already too highly impacted by pollutant load to provide adequate resolution of contributing impacts within the site.
- Sites on Onion Creek were dropped from Phase 2 due to the large contributing drainage area and resulting high discharge of Onion Creek confounding interpretation of potential impacts.

As shown in Table 1, not all scheduled sites were sampled during all sampling events due to circumstances beyond control, including:

- Bartholomew Park was not sampled in July 2016 because application of reclaimed water was temporarily halted prior to and during the July event due to damages to the irrigation system. Sampling at Bartholomew Park resumed immediately following the repair and subsequent resumption of irrigation system operation.
- Williamson at Pleasant Valley (site 10776) was originally intended to represent upstream conditions for the segment of Williamson Creek at Clay/Kizer golf course. However, it was predominately dry during the sample period. This site was replaced by Williamson at Dove Springs (site 3879) because the stream began producing baseflow near this section of Roy Kizer Golf Course. Accurate total stream discharge was difficult to measure at this location due to a portion of the discharge flowing through the cobble/gravel alluvial substrate. Although Williamson at Dove Springs was used to represent upstream conditions for Williamson Creek, based on its location relative to the golf course it may have already been impacted (and/or creek discharge produced) by the migration of golf course irrigation water.

Water samples were evaluated for conventional field parameters, nutrients, metals, ions and isotopes (Table 2). In addition to these parameters, the periphyton from rocks (epilithon) was collected from rocks randomly selected from within the riffles upstream and downstream of irrigation areas within Bartholomew Park, Roy Kizer, and the mainstem of Tannehill Creek at Morris Williams. As per City of Austin Standard Operating Procedures, rocks were collected from undisturbed areas in the riffle downstream of the water sample and before other sampling had occurred. Relatively flat rocks were selected to ensure a consistent sample area. An area of 19.6 cm^2 was scraped from each rock and placed into a shallow collecting pan (WRE SOP 2013). Each rock was rinsed with deionized water to flush epilithon from the rock. Material from nine rocks in each riffle was composited in the collection pan and then placed into one darkened sample bottle and one regular sample bottle with H_2SO_4 for preservation. Samples were analyzed for Chorophyll *a*, pheophytin, total organic carbon, total phosphorus, ammonia, nitrate+nitrite, and total Kjeldahl nitrogen. Total nitrogen was calculated by taking the sum of nitrate+nitrite and total Kjeldahl nitrogen. Chlorophyll *a*, total organic carbon, total phosphorus, and total nitrogen were then converted to mg/m^2 from mg/L.

Rainfall (inches) for the Williamson and Tannehill watersheds was downloaded from RainVieux and plotted with the monthly volume of reclaimed water irrigated at each site for the project's duration (October 2014 to December 2015). Total nitrogen in the water column, benthic carbon to phosphorus ratios (C:P), benthic carbon to nitrogen ratios (C:N), and benthic chlorophyll *a* were plotted for each sampling event in order to visualize the difference between upstream and downstream concentrations over time.

Table 2: Parameter List

Location	Site number and name	Water Type	Phase 1 Parameters	Phase 2 Parameters
Bartholomew Park	3858 Tannehill Creek @ Berkman Dr	creek	L, F, RS, I	L, F, RS
	10766 Tannehill downstream Bartholomew Spring	creek	L, F, RS, I	L, F, RS
	10767 Bartholomew Park Irrigation water	irrigation	L, F, I	L, F
	10765 Bartholomew Spring	spring	L, F, I	L, F
Hancock Golf Course	10773 Waller Creek @ 45th	creek	L, F, RS, I	
	625 Waller Creek @ 38th	creek	L, F, RS, I	
	10775 Hancock Irrigation Water	irrigation	L, F, I	L, F
Morris Williams Golf Course	843 Tannehill @ Lovell	creek	L, F, RS, I	L, F, RS
	10771 Tannehill @ MLK	creek	L, F, RS, I	L, F, RS
	10770 Morris Williams Central Trib upstream	creek	L, F, I	L, F
	10772 Morris Williams Central Trib downstream	creek	L, F, I	L, F
	10768 Morris Williams Irrigation Pond	irrigation	L, F, I	L, F
	10769 Moose Lodge Spring	spring	L, F, I	L, F
	10882 Tannehill 340ft downstream of Lovell	creek		L, F
Roy Kizer Golf Course	10776 Williamson downstream Pleasant Valley	creek	L, F, RS, I	L, F, RS
	3879 Williamson Creek at Dove Springs Park	creek	L, F, RS, I	L, F, RS
	661 Roy Kizer Spring	spring	L, F, I	L, F
	10778 Williamson downstream Roy Kizer Spring	creek	L, F, RS, I	L, F, RS
	10779 Roy Kizer Reclaim Water Pond	irrigation	L, F, I	L, F
	10883 Roy Kizer Reclaimed Water Pipe	irrigation		L, F
	65 Onion Creek at William Cannon	creek	L, F, RS, I	
	253 Onion Creek at McKinney Falls upper pool	creek	L, F, RS, I	
	662 Driving Range Spring	spring	L, F, I	

**Parameters: L = Lab F=Field RS=Rock Scrapings I=isotopes

Parameters collected during the sampling events included "Field", "Lab", "Rock Scraping" and "Isotopes" as described below. Due to the expense, only Phase 1 samples include isotopic evaluation. Springs, reclaimed water source, and sites without appropriate substrate did not include rock scrapings.

FIELD
Conductivity
Dissolved Oxygen
Temperature
pH
Stream Discharge (flow)

ROCK SCRAPINGS
Nitrate+nitrite as N
Ammonia as N
Total Kjeldahl Nitrogen as N
Phosphorus as P
Total Organic Carbon (TOC)
Chlorophyll *a*
Pheophytin

LAB
Metals (Ca, Mg, Na, K, Sr)
Ions (Cl, F, SO_4)
Alkalinity (Calcium Carbonate)
Nitrate+nitrite as N
Ammonia as N
Total Kjeldahl Nitrogen as N
Phosphorus as P
Orthophosphorus as P
Total Organic Carbon (TOC)

ISOTOPES
Nitrogen-15/Nitrogen-14 Ratio
Oxygen-18/Oxygen-16 Ratio

Analysis Methods

Two general methods were used to determine whether reclaimed water has an impact on adjacent water resources: inferential statistical analysis and theory. Inferential statistical analysis looks solely at the data and tests whether any structure in the data is from a disturbance or is merely due to random chance. Theory comes from the application of first principles and describes the mechanism by which the disturbance manifests itself. Thus, theory can not only predict whether an impact can be detected, but can also be used to estimate the magnitude of its impact. Additionally, any data collected can be used to validate the theory. In combination, these two methods can demonstrate a preponderance of evidence with inferential statistics providing a potential relationship among the data and the theory pointing to the likely causation of that relationship.

Inferential Statistical Analysis

To test whether there was an impact to the receiving water from reclaimed water irrigation; paired differences were calculated for each stream segment receiving reclaimed water. That is, for each site visit, concentration results from the downstream samples were subtracted from concentration results from the upstream samples. The average and standard deviation for these paired differences were calculated and then used to compute confidence intervals. This technique is used to improve the precision of the data by eliminating an additional source of variation (i.e. the variation that comes from taking samples at different times of the year).

Given paired differenced confidence intervals at each stream segment, one may compute the probability that the mean paired difference at each stream segment is equal to zero (i.e. not impacted). Thus, paired differences were calculated for each stream segment and for each analyte and ratio of nutrient concentrations (Gelman and Hill 2007).

Theory

A conceptual model can be used to express how a potential mechanism (e.g. irrigating reclaimed water) might impact an adjacent receiving stream. A plausible conceptual model might invoke mixing upstream water with a distributed loading of this irrigated water along the length of the creek to yield the downstream water composition. This model is graphically represented in Figure 4.

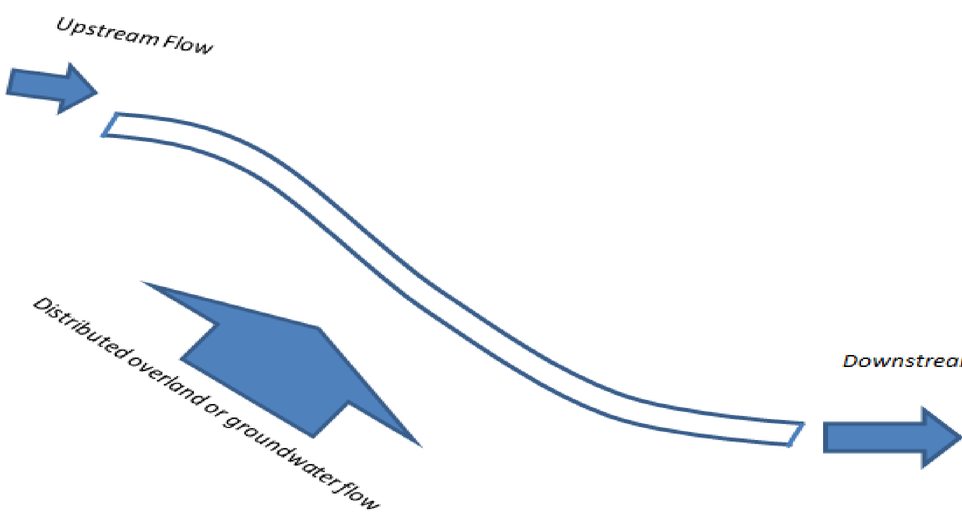

Figure 4: Schematic of reclaimed water irrigation conceptual model.

Applying Conservation of Mass, the mass entering a system must equal the mass exiting the system, assuming no storage within a stream segment. Thus, this model can be represented by:

$$\textit{Upstream mass flow rate} + \textit{Distributed mass flow rate} = \textit{Downstream mass flow rate} \quad (1)$$

or:

$$Q_{up} \cdot C_{up} + Q_{ReWW} \cdot C_{ReWW} = (Q_{up} + Q_{ReWW}) \cdot C_{down} \quad (2)$$

where Q_{up} = upstream flowrate (ft^3/s);
Q_{ReWW} = reclaimed water flowrate (ft^3/s);
C_{up} = upstream concentration (mg/L);
C_{ReWW} = reclaimed water concentration (mg/L); and
C_{down} = downstream concentration (mg/L).

Rearranging to solve for C_{down}:

$$C_{down} = F \cdot C_{up} + (1 - F) \cdot C_{ReWW} \quad (3)$$

where

$$\mathrm{F} = \frac{Q_{Up}}{(Q_{up} + Q_{ReWW})} \quad \text{and} \quad 1 - \mathrm{F} = \frac{Q_{ReWW}}{(Q_{up} + Q_{ReWW})}$$

From this, one can see that the downstream concentration is a flow-weighted mixture of upstream and reclaimed water concentrations. If there is no impact, then C_{down} would equal C_{up}, and F would equal unity. Unfortunately, determining F from field measurements of flow may prove difficult over the course of a season due to fluctuations in the flow. Furthermore, estimating the amount of Q_{ReWW} that contributes to the stream requires considerable assumptions on irrigation application rate. Additionally, there may be other influences on the stream, such as groundwater. For example, if there was an additional source to the stream (such as from groundwater) the conceptual model would not change too drastically. There would be an F_1 for the upstream contribution, an F_2 for the groundwater contribution, and a ($1-F_1-F_2$) for the reclaimed water. However, Equation 3 represents a simple and first iteration of a model, and it will be shown that this simplistic model may be a fair representation of the creek systems in the parks and golf courses.

To arrive at a practical (and long term) estimate of the impact from reclaimed water, it helps to look at the concentrations of the sampled downstream water relative to the upstream and reclaimed water concentrations. Equation 3 establishes that the downstream concentration is, in effect, a mixture experiment. That is, it is postulated that the downstream concentration is a mixture of upstream and reclaimed water concentration. Thus, data collected on the downstream concentration can be used to quantify the extent of this mixture. However, a suite of analytes, rather than a single constituent, is sampled in the surface water. Determining how this suite interacts with each other and their environment is difficult. To overcome this complexity, the geochemical computer program, pHREEQc (pH-REdox-EQulibrium) was used to simulate the chemical mixing of the upstream waters with reclaimed water under equilibrium conditions. The interaction of reclaimed water with the soil (itself a mixture of calcite and montmorillonite) was also simulated in an attempt to more accurately mimic the physical processes of the reclaimed water.

Using this approach, the model predicted downstream concentrations for each of the nine surface water analytes, given the upstream and reclaimed water data at each park. The goal was to determine which fraction, F, corresponded to the downstream surface water concentrations for all nine surface water analytes. Then, that fraction was compared to actual flow measurements, Q_{up} and $Q_{up}+Q_{ReWW}$, to validate the model. An additional validation using Piper plots is used to show the influence of downstream samples to either upstream samples or reclaimed water samples. The pHREEQc model, however, does not quantify the amount of nutrient (or chemical ion) uptake of algal biomass in the creek. However, the amount of chlorophyll *a* and any nutrient ratios can serve as an indication to the presence of this uptake and to the implication of an impact on the stream.

The conceptual model provides a framework with which to examine all of the data. One can postulate four different hypotheses using this overlying framework that can be tested using the data:

- Hypothesis 1 is that there is no impact on the stream. That is, the reclaimed water has been effectively absorbed into the soil without migrating to the stream. Under this scenario, inferences from the paired difference analyses of the surface water concentrations and the benthic ratios show no impact, and F is equal to, or approximately 1 (i.e. $F \simeq 1$).
- Hypothesis 2 is that there is an impact and can be seen in one of two potential data sets, the surface water data or the benthic ratio data. Thus, Hypothesis 2 is actually made up of two sub-hypotheses.
  - Hypothesis 2a is that there is an impact, but it is only on the surface water. Therefore, the nutrients have yet to be converted to algal biomass due to insufficient light conditions. Inferences from the paired difference analyses would not reveal an impact in the benthic ratios. Rather, the paired difference analyses would show an impact in the surface water and F is less than 1(i.e. $F < 1$).
  - Hypothesis 2b is that there is an impact, but it is only on the benthic substrate. Under this supposition, the reclaimed water irrigation is impacting the surface water, but algae are converting the composition of the water to benthic form. $F < 1$, but this can only be inferred from the paired differences in the nutrient ratios and cannot be inferred from the pHREEQc model.
- Hypothesis 3 is that an additional source is interfering with any impacts of the reclaimed water on the surface water; thus, confounding any inferences from the paired differences. Also, the flow ratio, *F*, would not be consistent among the nine surface water analytes. In this case, samples from this additional source would need to be obtained and the conceptual model (and pHREEQc model) would require a re-specification. A failure of the data sets to inform on the plausibility of either Hypotheses 1 or 2 may point to this Hypothesis.

The data from the cumulative sample periods of Phase 1 and Phase 2 are assessed under this framework to determine the presence or absence of an impact.

Results and Discussion

A cursory review of the data indicates that most downstream sites are higher in nitrogen than upstream sites, indicating that the creeks may be experiencing an impact from the application of high nutrient reclaimed water irrigation. However, it is important to thoroughly explore the data to ensure that the differences are statistically significant and can be attributed to the potential source.

The Methods section of this report describes an analytical model that provides three exclusive hypotheses to explore the data and explain the phenomena (i.e. characterize the change in the composition of downstream surface water). This section presents the empirical data and describes how it informs the possibility of one of the three competing hypotheses. The results of the sampling are evaluated in the context of four primary data sets. These sets are presented in the following order to substantiate the presence of an impact in the surface water, the percent contribution of the impact in the surface water, and characterize the impact in the surface water as follows:

1. **Confidence Intervals** of the mean paired differences in the surface water are depicted as bar graphs to serve as a preliminary indication of whether or not there is an impact to each of the creeks (Figures 5-12) and can be seen in tabular form in Appendix A. Additionally, confidence intervals of the mean benthic ratios of C:N, C:P and chlorophyll *a* (Figures 13-15) are presented

as further evidence of a potential impact as benthic communities uptake nutrients from the water column and may indicate impacts which might otherwise be hidden in the water column.

2. The **Geochemical pHREEQc model** estimates the percent contribution that the downstream water is influenced by the upstream water (Figures 16-19).

3. **Piper plots** are graphical depictions that distinguish different types of source waters and can be used to identify changes, trends, and mixing of ion compositions (Figures 21- 23).

4. **Total nitrogen along with benthic stoichiometry differences** are depicted in order to visualize differences in chemical and biological water quality from the potential impact (Figures 30-33).

The four data sets described above can be linked to the four hypotheses in the following manner:

- **Hypothesis 1** would be disproven if any of the confidence intervals (either surface water or benthic ratios) show a significant difference from upstream to downstream. That is, if the confidence intervals for the mean paired difference in the surface water or periphyton do not encompass zero, then that is an indication of an impact on the surface water.

- The Geochemical pHREEQc model can be used to examine the plausibility of **Hypothesis 2a and 2b**. The model provides an estimate of the percent contribution of upstream water and reclaimed water to the downstream water. If this percent contribution is consistent among a majority of the constituents sampled then that not only points to the source of the disturbance in the creek, but also to the amount of influence in the creek from reclaimed water. Further strength is given to this hypothesis if the analysis of confidence intervals also shows a non-zero confidence interval for each constituent in the creek. Flow measurements and piper plots can be used to validate this hypothesis.

- Finally, if the analysis provides insignificant results without a clear signal, then that may suggest **Hypothesis 3** (i.e. an alternative source of the impact) which would require more studies to determine the alternative source.

Confidence Intervals of the Mean Paired Differences

Confidence intervals of the mean paired difference in surface water parameters for each creek are presented in Figures 5 through 12. Bartholomew Park is shown first (Figures 5 and 6), followed by Morris Williams at the mainstem (Figures 7 and 8), Morris Williams at the central tributary (Figures 9 and 10), and finally Roy Kizer at Williamson Creek (Figures 11 and 12). The tabular results from this analysis can be found in Appendix A. Nitrate+nitrite is significantly higher in the downstream surface water sample (Figure 5) while there is a significant increase in the magnesium, potassium, sulfate, alkalinity, chloride, sodium, and calcium ions in the downstream surface water (Figure 6) at Bartholomew Park. The positive differences in these analytes imply surface water impacts from the reclaimed water irrigation at Bartholomew Park.

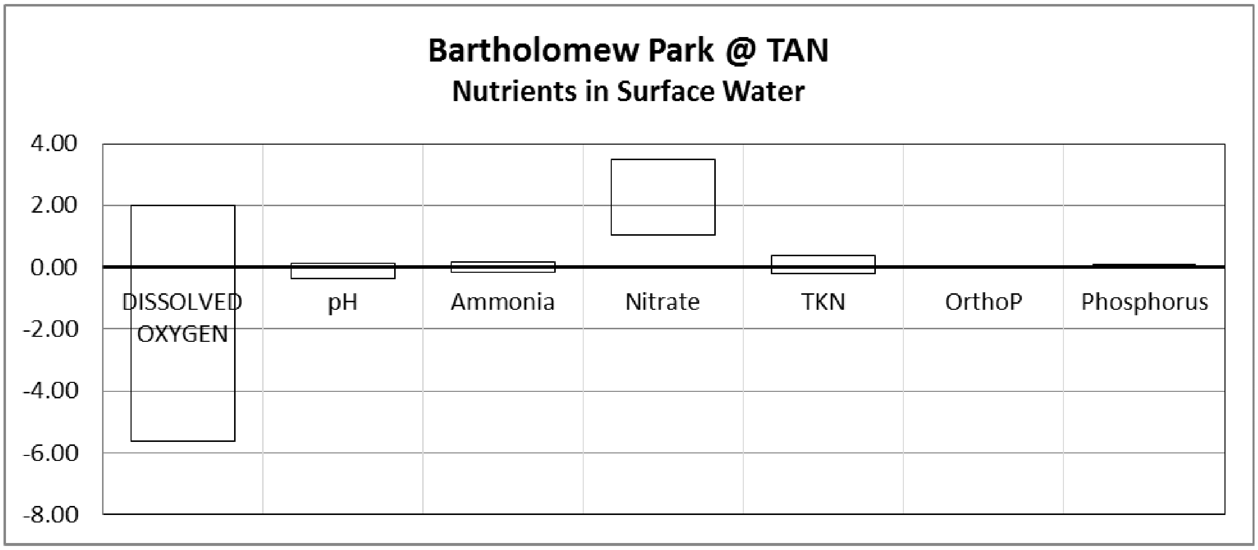

Figure 5: Confidence Intervals of the Mean Paired Difference of dissolved oxygen, pH, and nutrients in the water column collected upstream and downstream of Bartholomew Park. Nitrate was significantly higher in Tannehill Creek downstream of Bartholomew Park.

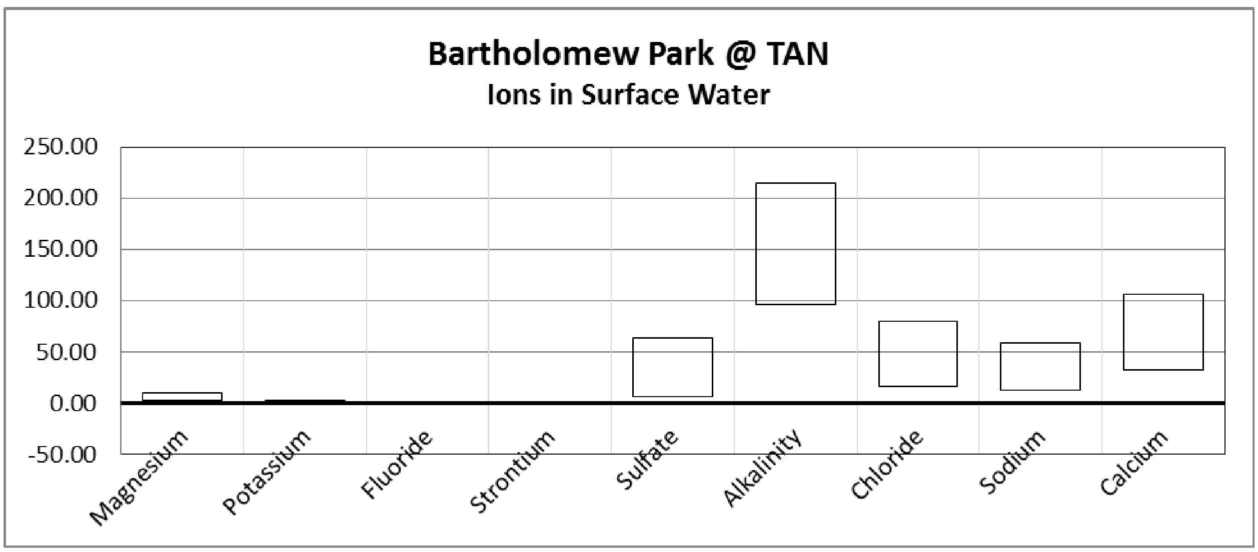

Figure 6: Confidence Intervals of the Mean Paired Difference of ions in the water column collected upstream and downstream of Bartholomew Park. Magnesium, potassium, sulfate, alkalinity, chloride, sodium, and calcium were all significantly higher in Tannehill Creek downstream of Bartholomew Park.

Figures 7 and 8 indicate that there is statistically no difference for most of the nutrients and ions in the surface water at Morris Williams in the mainstem of Tannehill Creek with three exceptions. Alkalinity and calcium ions are at concentrations *less* than upstream samples. TKN is at concentrations slightly higher than upstream. Thus, this particular analysis does not indicate a discernable impact from reclaimed water[1]. However, under the framework stated in the Methods section, there remains the possibility that any impact has been latent in the benthic algae data (Hypothesis 3) or is being diluted by

[1] Given the number of comparisons made in this report, a small but non trivial number of those comparisons may be expected to give a Type I error. It is possible, but cannot be verified with current data, that TKN is a false positive.

groundwater influence (Hypothesis 4). The most likely hypothesis for this creek will be determined from results for the pHREEQc model in the next section.

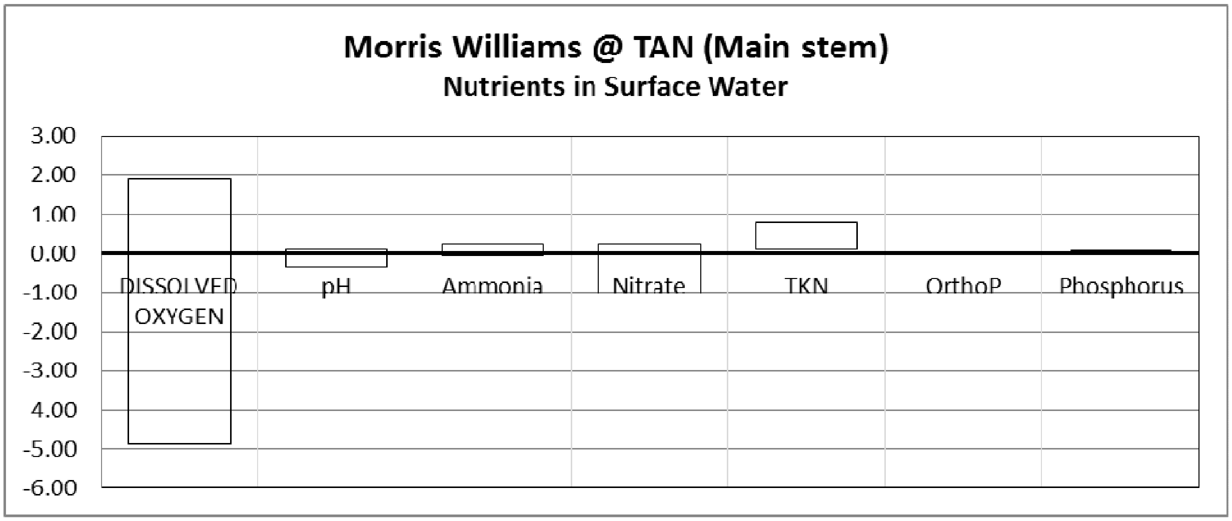

Figure 7: Confidence Intervals of the Mean Paired Difference of DO, pH, and nutrients in the water column collected upstream and downstream of Morris Williams. Of these parameters, only TKN was significantly higher in Tannehill Creek downstream of Morris Williams.

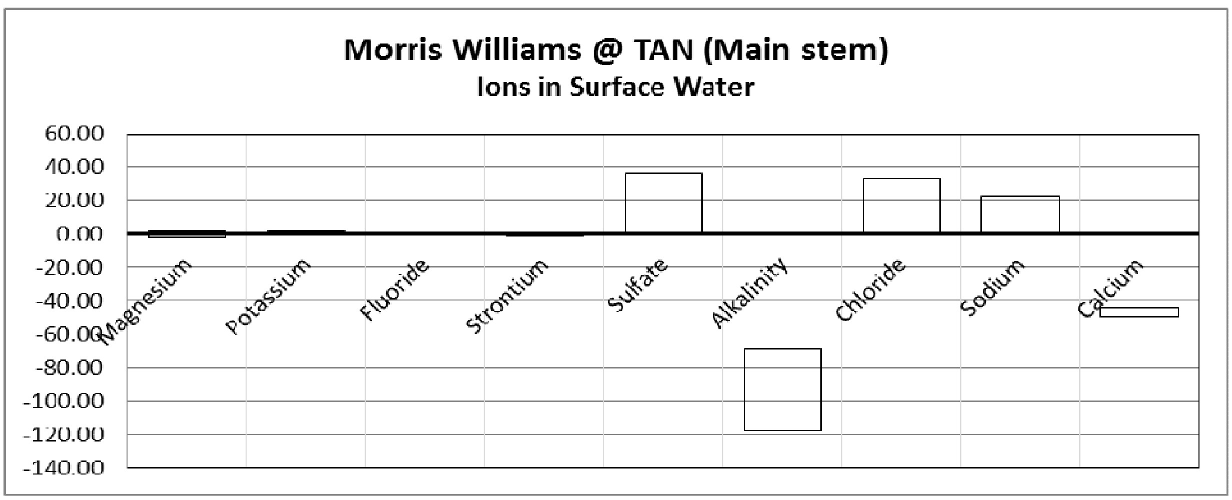

Figure 8: Confidence Intervals of the Mean Paired Difference of ions in the water column collected upstream and downstream of Morris Williams. Alkalinity and calcium were significantly lower in Tannehill Creek downstream of Morris Williams.

Similarly to Morris Williams mainstem of Tannehill Creek, Figures 9 and 10 below show that for the Morris Williams central tributary, differences between downstream and upstream samples were insignificant, with the exception of pH and nitrate.

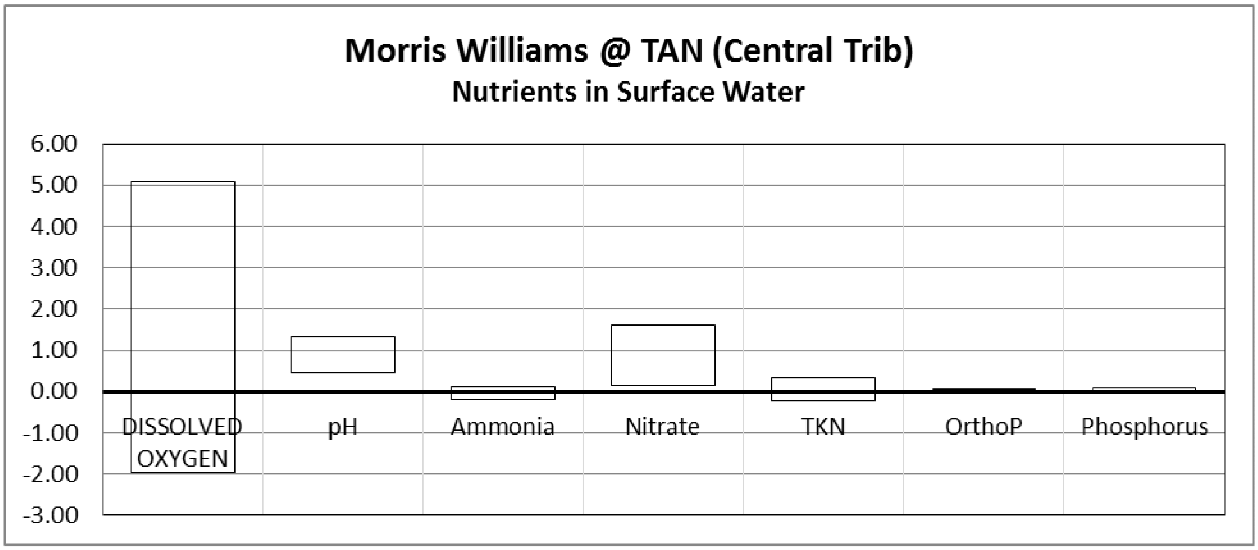

Figure 9: Confidence Intervals of the Mean Paired Difference of dissolved oxygen, pH, and nutrients in the water column collected upstream and downstream of Morris Williams within a tributary running through the golf course. Out of these parameters, only pH and nitrate were significantly higher in the tributary downstream of Morris Williams.

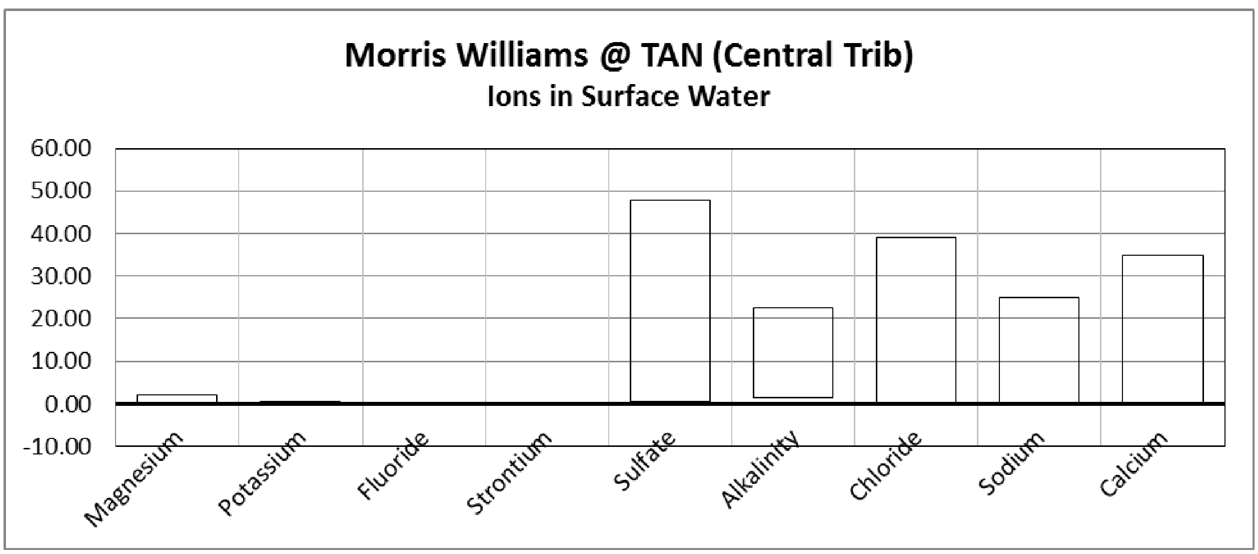

Figure 10: Confidence Intervals of the Mean Paired Difference of ions in the water column collected upstream and downstream of Morris Williams within a tributary running through the golf course. None of these parameter were significantly different in the tributary downstream of Morris Williams.

Results from Roy Kizer on Williamson Creek (Figures 11 and 12) showed impacts similar to that of Bartholomew Park. Nitrate+nitrite concentrations in downstream samples were higher than upstream samples and most of the downstream samples showed elevated ion concentrations compared to upstream indicating that there was a statistically significant impact to the surface water

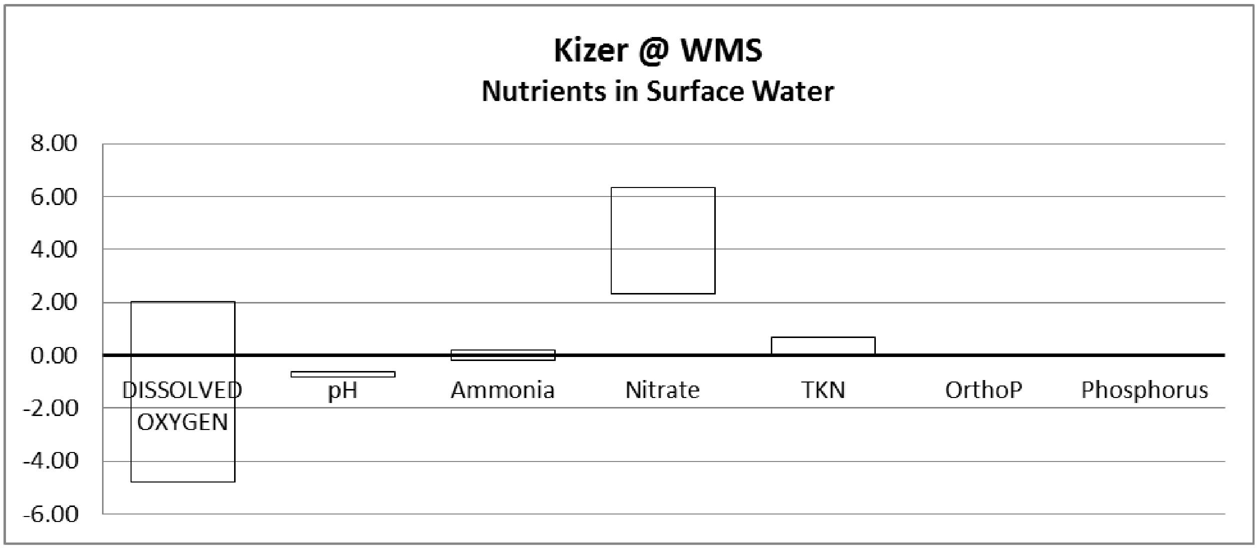

Figure 11: Confidence Intervals of the Mean Paired Difference of dissolved oxygen, pH, and nutrients in the water column collected upstream and downstream of Roy Kizer. Nitrate was significantly higher in Williamson Creek downstream of Roy Kizer while the pH was significantly lower.

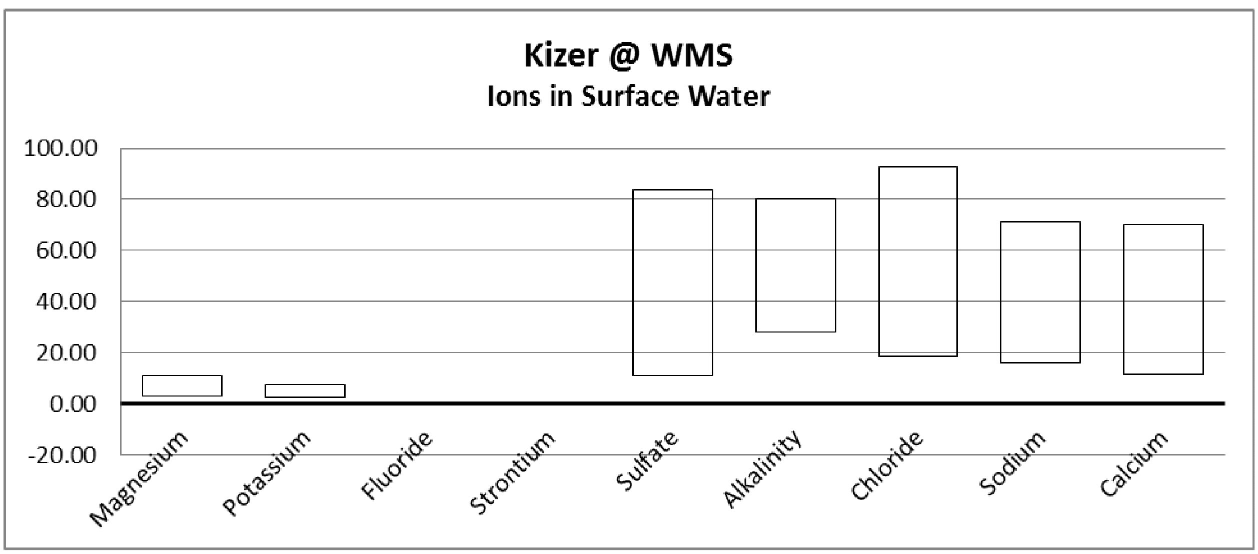

Figure 12: Confidence Intervals of the Mean Paired Difference of ions in the water column collected upstream and downstream of Roy Kizer. Magnesium, potassium, sulfate, alkalinity, chloride, sodium, and calcium were significantly higher in Williamson Creek downstream of Roy Kizer.

Based on the confidence intervals of the mean paired difference in surface water parameters for each creek, there appears to be statistically significant differences in samples taken between upstream and downstream locations at Bartholomew Park and at Roy Kizer. Differences in surface water samples taken between upstream and downstream samples at the two tributaries in Morris Williams were more ambiguous. However, the next set of confidence intervals to be discussed (regarding the benthic ratios) reduces that ambiguity.

None of the creeks sampled showed any differences in fluoride or strontium concentrations. It is suspected that fluoride, which is a negatively charged ion, is only attenuated by vegetation, since cation ion exchange with clay in soil is unlikely due to the negative charge of clay. Plant uptake studies using fluoride-rich irrigation water show that fluoride accumulates in various plant parts. The root accumulates most of the fluoride supplied through irrigation water (Pollick 2004).

Confidence Intervals of the C:P, C:N and benthic chlorophyll *a*

Results for the benthic C:P, benthic C:N, and benthic chlorophyll *a* content of samples collected upstream and downstream of irrigation sites are displayed in Appendix C with additional graphs in Appendix D. Benthic C:P significantly decreased from upstream to downstream as demonstrated by a mean paired difference confidence interval that did not include zero (Table 3). There was no significant difference from upstream to downstream for benthic C:N or benthic chlorophyll *a* as the individual confidence intervals each contained zero.

Table 3: Mean paired difference (95% confidence interval) in the benthic C:P, benthic C:N, and benthic chlorophyll *a* content computed downstream to upstream. The probability that the difference is strictly positive or negative is also included. A decrease in the benthic ratios or increase in the chlorophyll *a* content would show degradation downstream.

Parameter	Mean Difference	95% CI	Prob > 0	Prob < 0
Carbon to Phosphorus	-6.48	(-10.49,-2.76)	--	1.0
Carbon to Nitrogen	-0.71	(-1.96,0.38)	--	0.89
Chlorophyll *a*	16.72	(-23.26,53.58)	0.821	--

The decreasing pattern in the benthic C:P (Figure 13A) suggests an increase in phosphorus load to the creek which was not detectable in the water column, possibly due to nutrient uptake by the benthic algae. This is most pronounced in samples collected in the mainstem of Tannehill creek upstream and downstream of the Morris Williams golf course (Figure 13B).

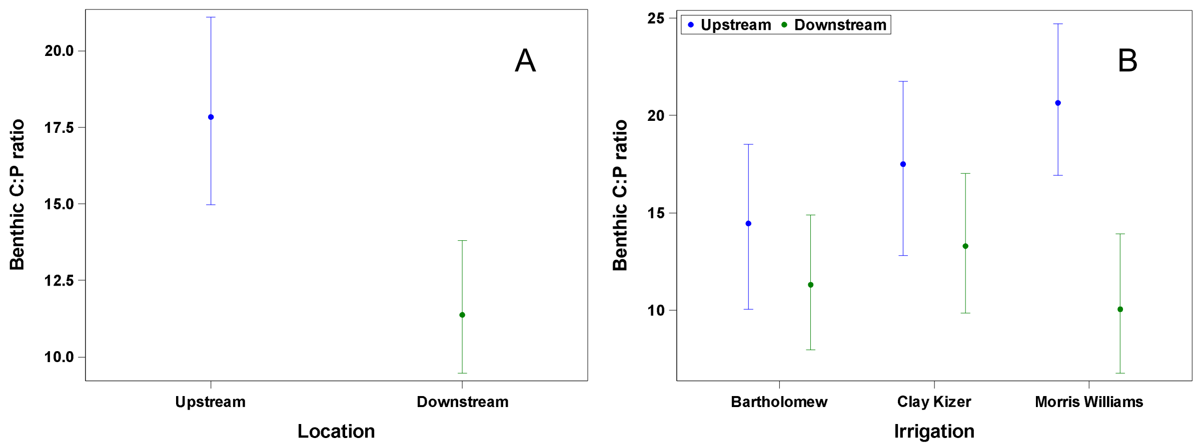

Figure 13: The mean and 95% Confidence Interval of benthic Carbon (C) to Phosphorus (P) in upstream and downstream samples pooled from all reclaim irrigation sites (A), and partially pooled for distinction between each reclaimed irrigation site (B). The benthic C:P was significantly lower downstream of reclaimed irrigation sites.

There was no significant pairwise difference in benthic C:N upstream and downstream of the reclaimed water irrigation sites. There was a decreasing pattern in the benthic C:N (Figure 14A) which would indicate degradation downstream of the irrigations sites and the probability of the difference to be below zero was 0.89 based on the data collected. This suggests that the decreasing pattern might be real and not a random phenomenon. Given several more sampling events, the pairwise difference in C:N upstream and downstream of the irrigations sites might be determined to be significant.

The variability for benthic C:N in all upstream site locations was much higher than the variability at downstream locations (Figure 14B). This was most likely due to a high benthic C:N collected upstream of Clay Kizer in October 2014. This would impact the variability at all upstream sites because the data is partially pooled and not analyzed separately.

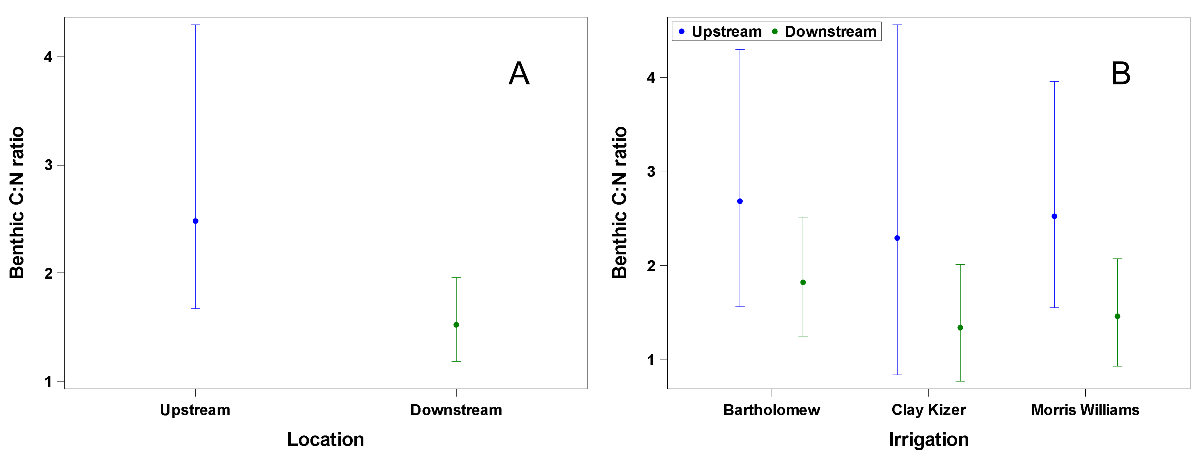

Figure 14: The mean and 95% Confidence Interval of benthic C:N in upstream and downstream samples pooled from all reclaimed irrigation sites (A), and partially pooled for distinction between each reclaimed irrigation site (B). There was no significant pairwise difference in benthic C:N upstream to downstream.

There was not a significant difference in benthic chlorophyll *a* (mg/m^2) upstream to downstream of the reclaimed water irrigation sites. While it appeared that there were higher chlorophyll *a* concentrations downstream of irrigation sites when all of the data was pooled (Figure 15A), the parameter was highly variable and no clear pattern was discernible based on pairwise comparisons. The probability for chlorophyll *a* concentrations to be higher downstream of the irrigation sites was only 0.821 and it is unclear what inference further sampling would lead to without the inclusion of more explanatory variables. Chlorophyll *a* concentrations at Bartholomew showed more signs of degradation than did the other two irrigation sites (Figure 15B). The Bartholomew Park irrigation site may be impacting Tannehill Creek upstream of the Morris Williams golf course irrigation site.

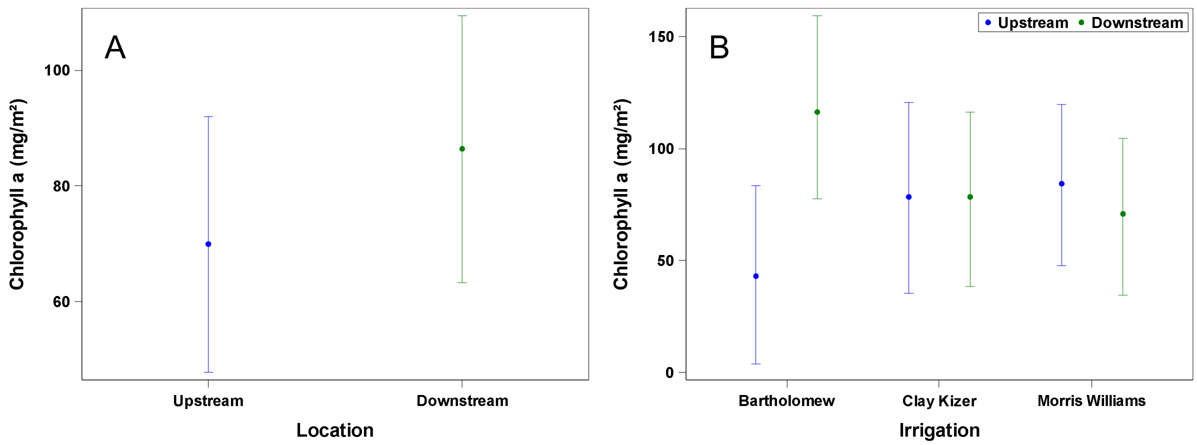

Figure 15: The mean and 95% Confidence Interval of benthic algae chlorophyll *a* (mg/m^2) in upstream and downstream samples pooled from all reclaimed irrigation sites (A), and partially pooled for distinction between each reclaimed irrigation site (B). There was no significant pairwise difference in benthic chlorophyll *a* upstream to downstream.

Geochemical pHREEQc Model

Analysis of the confidence intervals on Bartholomew Park and Roy Kizer infers an impact to surface water from reclaimed water irrigation. If this is true, it should be supported by pHREEQc modeling. The overarching framework postulated in the Methods section suggests that any contribution to the downstream samples originate from a flow-weighted mixture of two sources: upstream water and reclaimed water. This section examines the influence of these two samples on the downstream sample. Medians of the upstream and reclaimed water concentration samples were input into the model (see Appendix B for the values). Table 4 shows an estimate of the downstream concentration under either solely upstream influenced conditions or under solely reclaimed water influenced conditions for the nine key ions collected in the surface water.

Table 4: Estimated downstream concentrations (mg/L) from the pHREEQc model under solely upstream influenced conditions and solely reclaimed water influenced conditions.

	Cl^-	Na^+	Mg^{+2}	K^+	SO_4^{-2}	F^-	NO_3^-	Alk	Ca^{+2}
Bartholomew Park @ TAN									
Upstream	15.5	12.5	3.6	2.3	13.9	0.3	0.1	108	44.4
ReclaimedWW	113.6	120.2	25.1	14.4	134.6	1.9	29.1	382	161.6
Morris Williams @ TAN (mainstem)									
Upstream	34.0	25.4	5.4	1.9	30.2	0.3	0.7	243	102.0
ReclaimedWW	113.0	120.7	25.4	14.4	134.6	1.9	29.1	382	161.1
Morris Williams @ TAN (central tributary)									
Upstream	16	19.7	4.6	2.6	10.8	0.4	0.3	210	72.2
ReclaimedWW	113.0	120.7	25.2	14.4	134.6	1.9	29.1	382	158.4
Roy Kizer @ WMS									
Upstream	31.0	20.0	7.3	2.2	33.2	0.28	0.7	200	83.2
ReclaimedWW	132.1	84.2	14.5	5.4	125.9	0.43	9.0	282	187.7

If the conceptual model is close to reality, then the concentrations of the downstream samples should be between the upstream and reclaimed water concentrations bounds, inclusively, given in Table 4 for each ion for each park. Downstream samples with concentrations close to those of upstream samples would be mostly upstream influenced, whereas downstream samples with concentrations close to those of the model-predicted reclaimed water samples would be mostly influenced by reclaimed water.

Applying the conceptual model also gives the advantage that the fractional amount of influence, *F*, from each source can be inferred. The results from the model can be superimposed on the confidence intervals of the mean concentration for each constituent under upstream, downstream, and reclaimed water samples in Bartholomew Park (Figure 16).

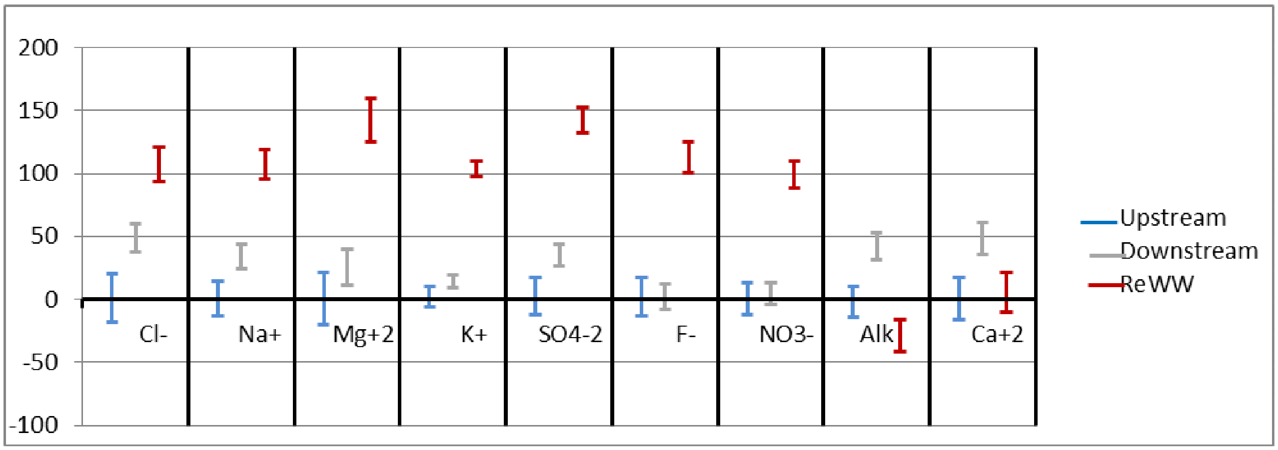

Figure 16: Bartholomew Park pHREEQc Results. The blue, grey, and red bars represent the 99% confidence intervals of the mean concentration for each analyte. Confidence intervals are standardized to a scale of 0 to 100 where 0 denotes the pHREEQc model prediction of the upstream concentration and 100 signifies the pHREEQc model prediction of the reclaimed water after its interaction with the soil. With the exception of fluoride and nitrite, the confidence intervals of the nine downstream constituents (grey bars) encompass approximately a score of 40 on the y-axis. This indicates a 40% contribution from reclaimed water.

As an example to aid interpretation, the pHREEQc model for Bartholomew Park predicted that if only upstream waters were influencing the downstream waters, the downstream samples would have a chloride concentration of 15.5 mg/L (see Table 4) or a standardized score of 0 (i.e. 0% reclaimed water) (see Figure 16). If reclaimed water was the only influence on the downstream sample, then the downstream samples would have a chloride concentration of 113.6 mg/L or a standardized score of 100 (i.e. 100% reclaimed water). The confidence intervals on the mean concentrations for the upstream and reclaimed water samples include (as it should) the 0 and 100 scores, respectively. The confidence intervals of the mean concentrations of the downstream samples, however, all cluster around the score of approximately 40. Thus, one may infer that the downstream waters are composed of 40% reclaimed water and 60% upstream water, which is consistent with paired difference results. Furthermore, flow measurements taken during the sample visits indicate that *F*, the fraction of upstream to downstream flow, averages at about 60%. This is consistent with the pHREEQc results and verifies an impact to the stream at Bartholomew Park (Figure 16).

The Bartholomew Park pHREEQc model predicted alkalinity and calcium concentrations of 382 mg/L and 162 mg/L, respectively, for a purely reclaimed water downstream sample, when the actual reclaimed water sample had concentrations of 28 mg/L and 50 mg/L, respectively. This may indicate that as the reclaimed water is moving through the soil, it is dissolving the calcium in soil and transporting this calcium with it. This may explain why the alkalinity and calcium concentrations in the downstream samples are much higher than that of the upstream or reclaimed water concentrations. Similarly, the pHREEQc model predicted that magnesium concentrations in purely reclaimed water downstream sample would be much lower than that of the actual reclaimed water concentration. This indicates that as the reclaimed water is moving through the soil, it is losing magnesium.

Fluoride and nitrate+nitrite concentrations in the downstream sample do not appear to adhere to the pattern predicted for other constituents at Bartholomew Park. One explanation may be the limited nature of the pHREEQc modeling attempted for this report. Nitrate+nitrite will undergo a conversion to another species that was not input into the model. For fluoride, it is hypothesized that the soil will adsorb the fluoride to make fluorite using a reaction not yet programmed into pHREEQc.

With Bartholomew Park results presented in detail as a case study, modeling results for the remaining creeks can be discussed briefly. The impact from the reclaimed water on the surface water of Morris Williams is either subdued owing to large variability in the samples or non-existent (Figure 17-18). The confidence intervals also show that the surface water in the main stem is losing alkalinity and calcium as it advances downstream. Alkalinity and calcium in the central tributary, on the other hand, are highly variable with both downstream and upstream samples showing similar concentrations. Flow measurements indicate that estimates of F, the fraction of upstream to downstream flow, is about 90%, which may explain the lack of an impact on surface water on the main stem. Thus, nutrient ratios for this park may be needed to ascertain an impact.

For the central tributary, however, flow upstream is greater than downstream for two of the four site visits removing the possibility of verifying the actual flow measurements with the pHREEQc results. This variation of flow in time also emphasizes that flow is a confounding factor in the analysis for this creek. Since pHREEQc gave consistent results of F, groundwater influences may be ruled out.

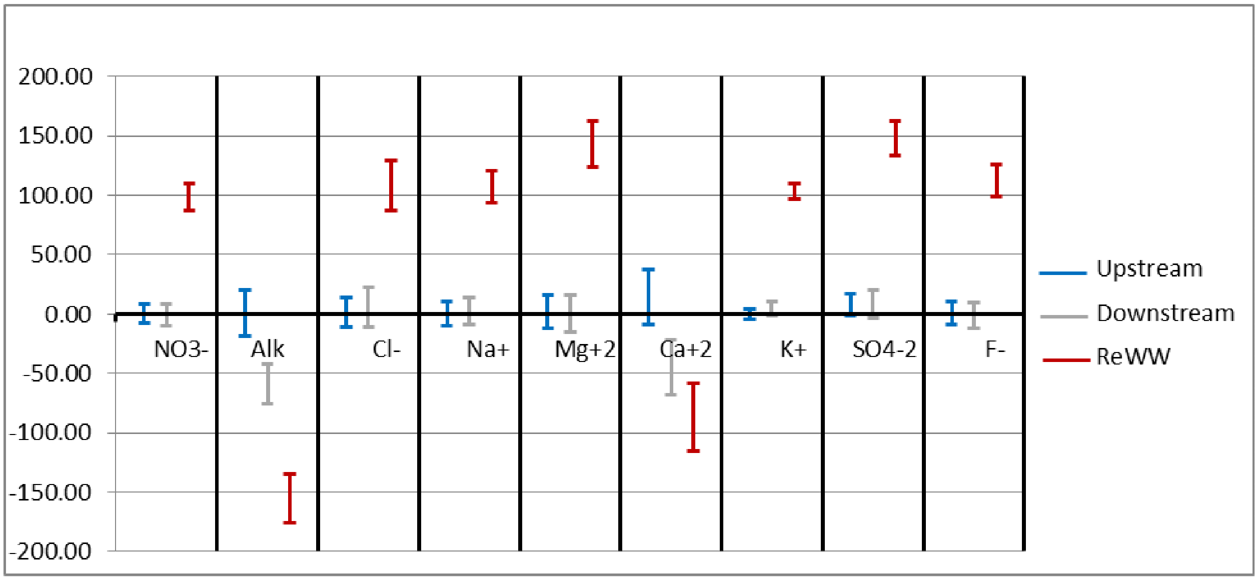

Figure 17: Morris Williams (main stem) pHREEQc Results. The blue, grey, and red bars represent the 99% confidence intervals of the mean concentration for each analyte. Confidence intervals are standardized to a scale of 0 to 100 where 0 denotes the pHREEQc model prediction of the upstream concentration and 100 signifies the pHREEQc model prediction of the reclaimed water after its interaction with the soil. With the exception of alkalinity and calcium, the nine downstream constituents (grey bars) contain a score around zero. This indicates a negligible to small impact on the downstream concentrations from reclaimed water. Benthic ratios are needed to determine the presence of an impact.

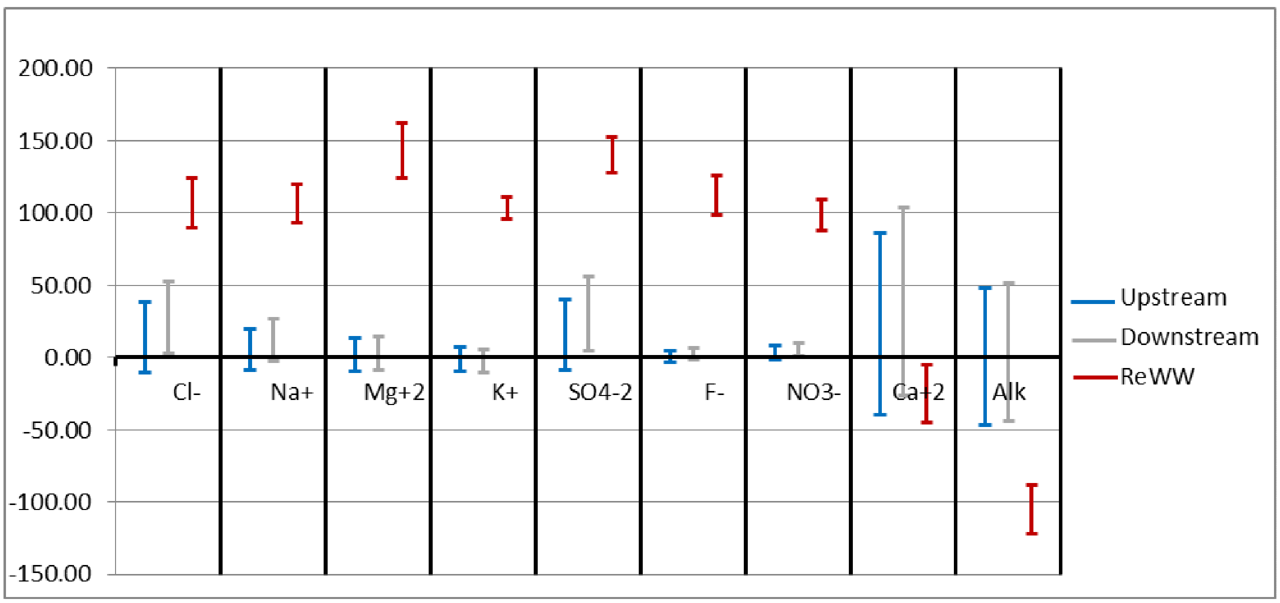

Figure 18: Morris Williams (central tributary) pHREEQc Results. The blue, grey, and red bars represent the 99% confidence intervals of the mean concentration for each analyte. Confidence intervals are standardized to a scale of 0 to 100 where 0 denotes the pHREEQc model prediction of the upstream concentration and 100 signifies the pHREEQc model prediction of the reclaimed water after its interaction with the soil. The downstream constituents (grey bars) have considerable variability making any assessment of impact on the creek difficult. Benthic ratios are needed to determine the presence of an impact.

The impact of the reclaimed water on surface water at the Roy Kizer golf course was similarly assessed (Figure 19). Potassium shows the clearest indication of an influence from reclaimed water at around 30%. This estimate of 30% is certainly within the bounds for chloride, sodium, and magnesium; however, the variability for these analytes dominates any inference that can be made from it. Again, the flow measurements are not consistent across the sampling visits. This makes verification of the pHREEQc model unfeasible. This variation in flow may be contributing to the variability at the site. There exists some variation in the *F* inferred from pHREEQc (Figure 19), which is pointing to a groundwater influence. But given that the paired differences showed an impact in the surface water, this groundwater influence may be considered small relative to the influence of reclaimed water.

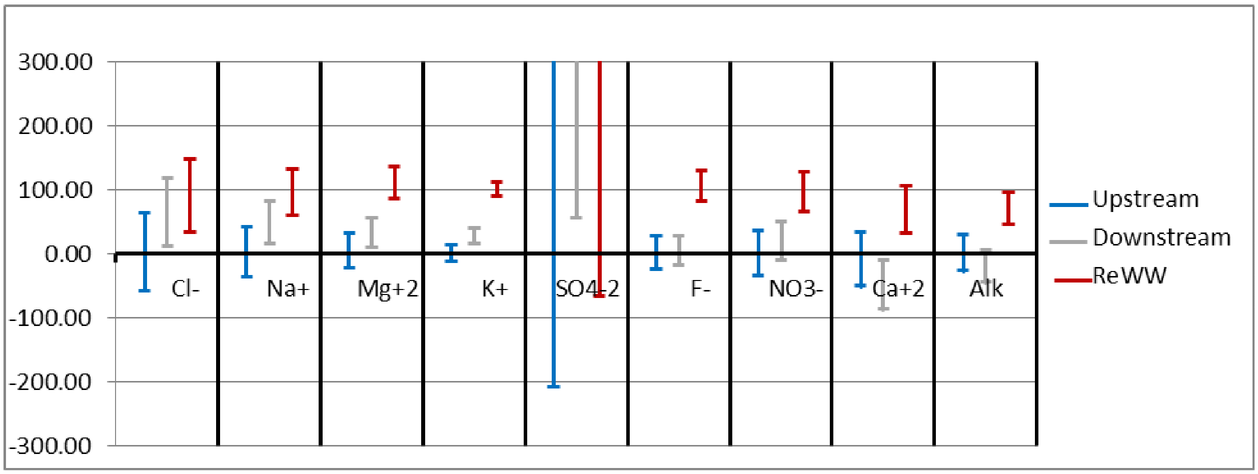

Figure 19: Roy Kizer pHREEQc Results. The blue, grey, and red bars represent the 99% confidence intervals of the mean concentration for each analyte. Confidence intervals are standardized to a scale of 0 to 100 where 0 denotes the pHREEQc model prediction of the upstream concentration and 100 signifies the pHREEQc model prediction of the reclaimed water after its interaction with the soil. The downstream constituents (grey bars) show about a 30% impact due to reclaimed water for chloride, sodium, magnesium, and potassium. The variability in sulfate is extensive and precludes an inference, while downstream concentrations of fluoride and nitrite characteristically show no influence. Downstream concentrations of calcium and alkalinity also appear to show little to no influence due to reclaimed water

<u>Piper Plots</u>

Piper plots, or triangle plots, are typically used to determine the hydrogeochemical facies or classification of natural water. In natural water, the ion composition is controlled by local lithology, the duration of the water-rock and the water-soil interactions, and natural attenuation. In the Austin area, groundwater and surface water is classified as a calcium-bicarbonate hydrogeochemical facies due the carbonate geology that dominates most of the area.

Natural, native groundwater with calcium-bicarbonate hydrogeochemical facies will plot on the left hand side of the diamond-shape area of a piper plot. In contrast, reclaimed water from Austin's municipal supply is considerably higher in sulfate and chloride, and will consequently plot on the right hand side of the diamond-shaped area (Figure 20). The mixing of two distinctly different water types will result in a shift in the ion composition at an impacted monitoring site. In a piper plot, mixing would be indicated if downstream points plot in-between the natural waters on the left and reclaimed water on the right. The magnitude and direction of the linear shift of creek water facies toward the reclaimed water facies would indicate the degree of mixing with or influence from the reclaimed water. Larger shifts will indicate greater amounts of reclaimed water mixing with the natural groundwater or surface water. The magnitude of the shift is also influenced by antecedent weather conditions, creek flow, and irrigation rates. For example, the shift can be muted during high rainfall periods because irrigation rates generally decrease and rainwater runoff has lower concentration of ions.

The mean ion concentrations for calcium, magnesium, potassium, sodium, bicarbonate, chloride, and sulfate at the upstream, the downstream, and the reclaim water monitoring sites are characterized with a piper plot (Figure 20). Each point shown in the diamond-shape and triangular areas is a graphical representation of all ion concentrations reported as the overall percentage of the total cation and anion concentrations.

Consistent with the preliminary results of Phase 1 of this study (Clamann et al. 2014), there is a clear shift in the ion concentrations of downstream samples from a more natural condition towards the more sulfate and chloride-rich composition of reclaimed water (Figure 20). This indicates that reclaimed water is likely mixing with the surface water. The ion composition varies between reclaimed water sources. The reclaimed water irrigated at Bartholomew Park and at Morris Williams Golf Course has a higher sulfate, chloride, and magnesium concentration then the reclaimed water irrigated at Roy Kizer. A similar variation in magnesium concentrations at the springs located on the golf courses that were irrigated with reclaimed water is also reported in a 2007 study (Hiers and Herrington 2007). The variation may be attributed to differences in the chemical composition of the wastewater stream that the two treatment plants (the Walnut Creek Wastewater Treatment Plant and the South Austin Regional Plant) are processing and distributing to the reclaimed water system.

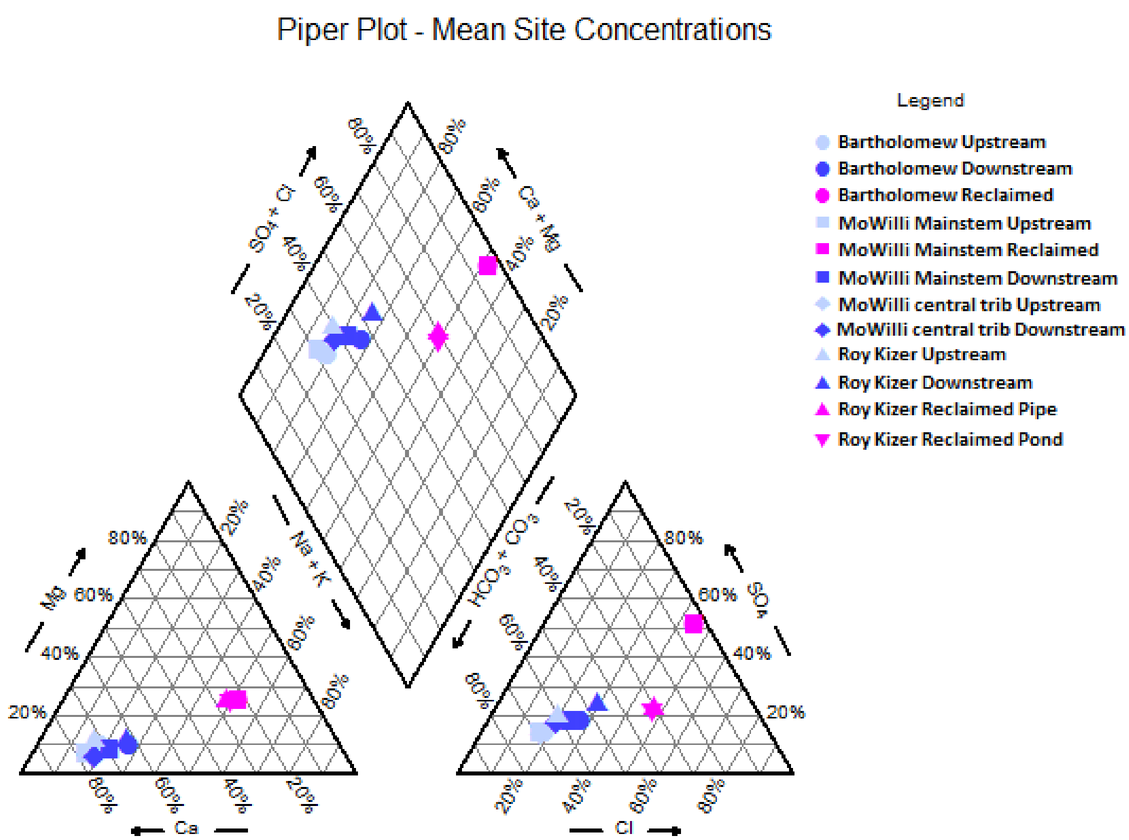

Figure 20: The mean ion concentrations for calcium, magnesium, potassium, sodium, bicarbonate, chloride and sulfate at the upstream, the downstream and the reclaim water monitoring sites.
Upstream sites are in light blue. Downstream sites are in dark blue. Reclaimed Water sites are in purple

Piper plots, of the pHREEQc model ion data for the upstream, the downstream, and the reclaimed water sites was constructed (Figure 21). The plots generally show the same drift in the ion data indicative of reclaimed water mixing with natural water at the downstream monitoring sites, with the exception of the

Morris Williams mainstem monitoring site. The Morris Williams mainstem site simulated ion data is different in that the ion data shows little to no variability and no significant difference in ion composition at the downstream site. This suggests that the upstream site may already be impacted by reclaimed water irrigation activities further upstream at Bartholomew Park and/or Mueller Development, which are located upstream of the Morris William Golf Course. However, it is also plausible that irrigation rates in this portion of the golf course were lower so that natural attenuation from the interaction with the soil and vegetation is sufficient to mute measureable effects in the downstream water chemistry.

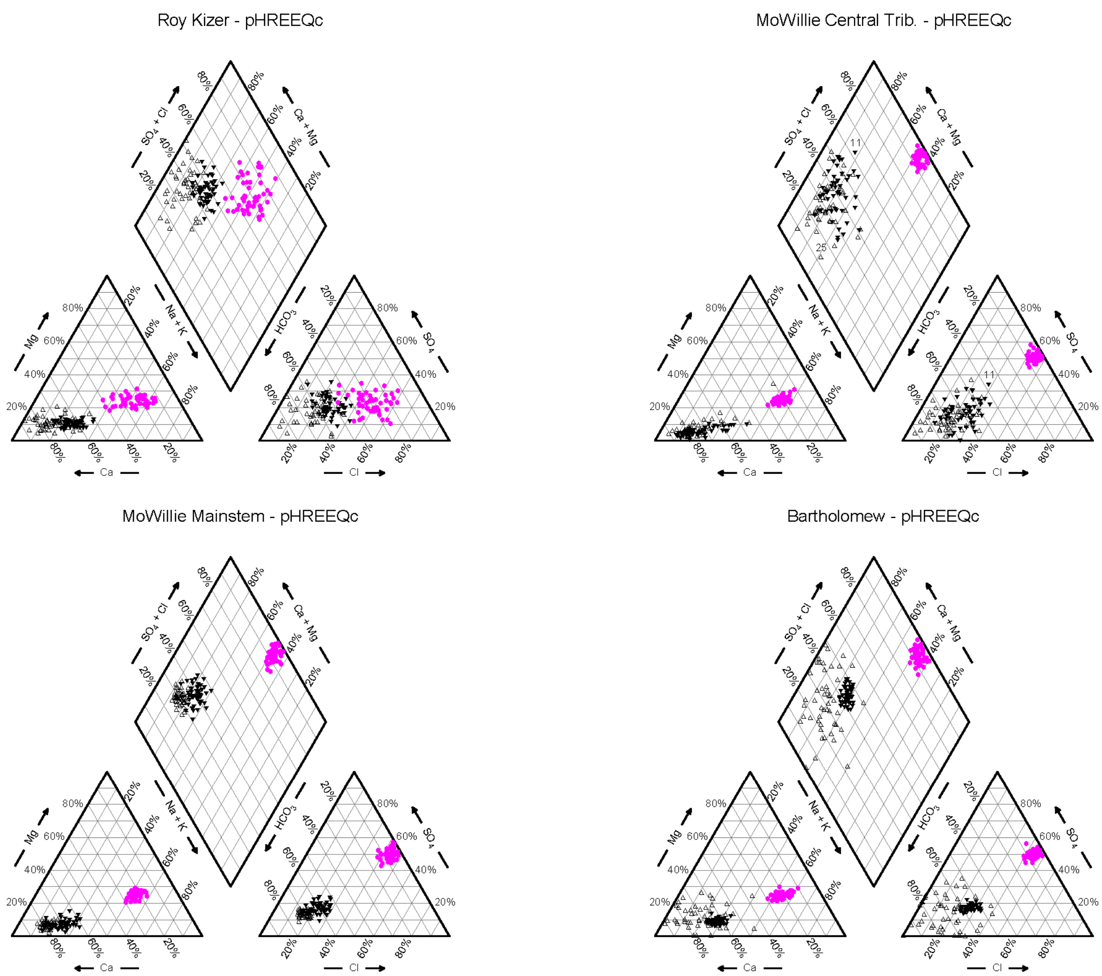

Figure 21: Piper plot of the pHREEQc model ion data for the upstream, the downstream, and the reclaimed source water at each of the study stream reaches

△ = Upstream sites   ▲ = Downstream sites   ● = Reclaim Water sites

<u>Temporal Trends at Roy Kizer Spring</u>

The Williamson Creek Wastewater Treatment Plant was closed and decommissioned in the early 1970's. Construction of the Roy Kizer Golf Course started in 1994 on the site of the old plant. Around this time the City of Austin discovered that the springs and seeps along Williamson and Onion creeks adjacent to the old treatment plant site had very high nitrate and ammonia concentrations. The δ^{15} Nitrogen isotope samples collected in August 1993 had ratios of 11.6 and 12.9, indicating a biogenic source. Using nitrogen isotope analysis, the nitrogen source was traced to sediment and sludge from the abandoned treatment plant sludge pits. To remediate this impact, during the construction of the golf course the sludge material was stocked piled and saved for use as top dressing for the greens, tee boxes, and fairway areas so that the turf grass could utilize the nutrients within the sludge. The remediation effort was apparently successful in reducing the elevated nitrate levels observed at several springs along Williamson and Onion creeks, including Roy Kizer Spring (Figure 22). A time-series plot of nitrate+nitrite concentrations at Roy Kizer Spring from 1996 to present indicates a sharp drop in nitrate+nitrite concentration during the first four years after construction of the golf course. This reduction in nutrients were presumably due to the remediation efforts as the newly installed turf grass consumed the nitrogen from nutrient-rich sediment and sludge mixture used as top dressing. By 1998, the nutrient concentrations in spring discharge had decreased to less than 5 mg/L of nitrate+nitrite as nitrogen.

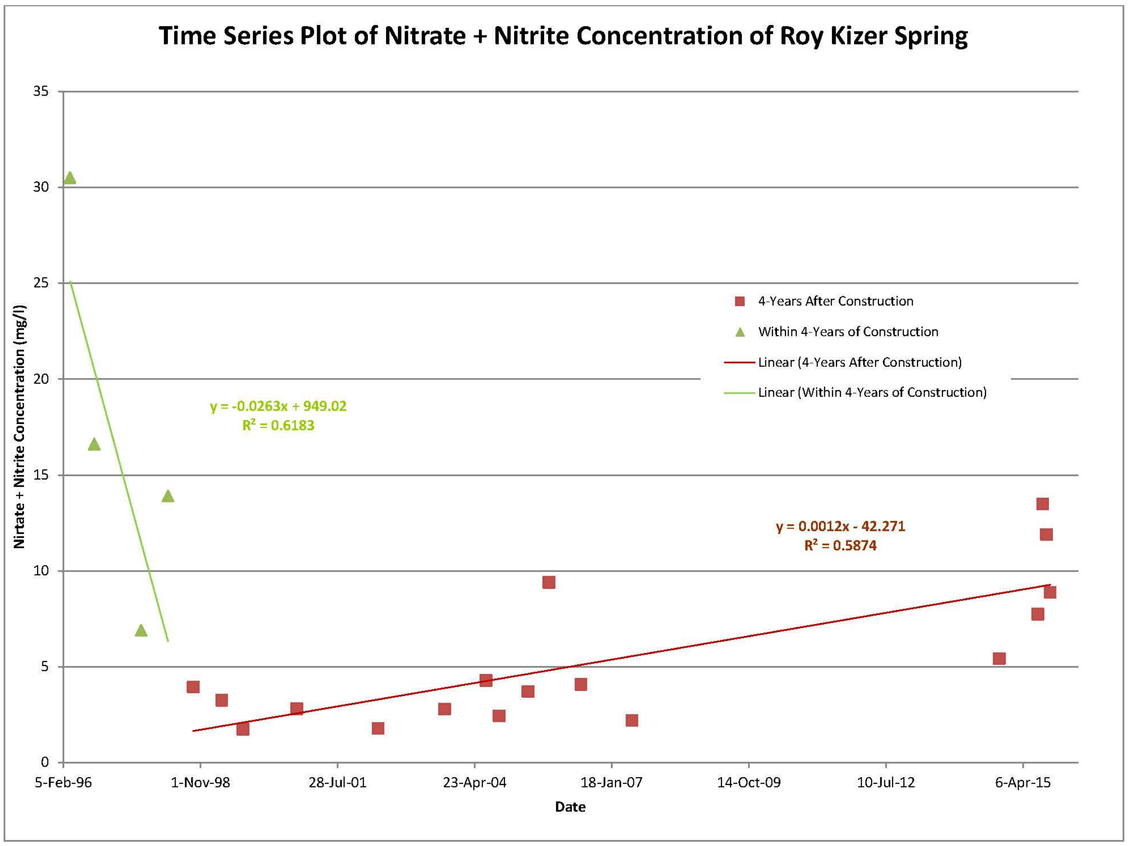

Figure 22: Time-series plot of nitrate+nitrite concentration at Roy Kizer Spring

Based on nitrate levels collected since 1998 and most recently in 2014 and 2015 associated with this study, it appears that nitrate+nitrite concentrations have recently increased to between 5 mg/L and 15 mg/L (Figure 22). Nitrogen concentrations in this range are unusually high for Austin area groundwater which typically has concentrations around 2 mg/L. Of the 2,693 nitrate+ nitrite observations collected by the City of Austin from Austin-area springs from 1968 to present, the 10 highest values were collected from springs on the Jimmy Clay and the Roy Kizer golf courses. Of interest to this study, the 10th highest nitrate+ nitrite value was collected during the recent field efforts on August 27, 2015, at Roy Kizer Spring. Since the Roy Kizer Springshed is located entirely within the golf course, the source of the biogenic influence may be the application of reclaimed water irrigation.

In addition to the spatial differences observed in the ion data between upstream and downstream sites, increases over time in sulfate and chloride concentrations may be observed at Roy Kizer Spring. The spring has occasionally been monitored by the City of Austin since the mid-1990's. Sixteen samples have been collected since August of 1996 to present (Figure 23). Piper plots indicate that the groundwater discharge from the spring is enriched with sulfate and chloride likely from reclaimed irrigation water similar to that as shown in the previously described spatial comparison between upstream and downstream sites and the pHREEQc modeled results. Since the springshed for this spring is located entirely within Roy Kizer Golf course, the source for the increase is most likely reclaimed water irrigation and grass management practices.

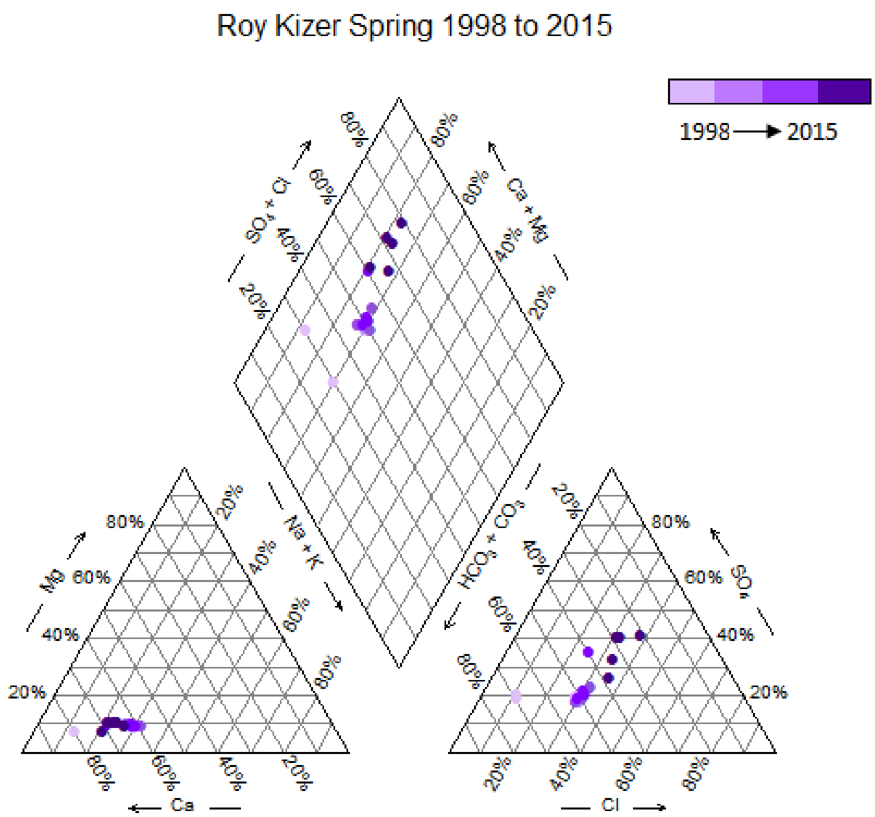

Figure 23: Piper plot of ion data collect at Roy Kizer Spring from August 1998 to December 2015. Note the temporal trend in the middle and right-hand plots that indicate a shift in the composition.

Bivariate plots of specific conductance and nitrate+nitrite nitrogen

Since 1992, the City of Austin Watershed Protection Department has been periodically monitoring selected springs adjacent to several golf courses. At least 25 springs from nine different golf courses have been monitored over the past 25 years. The golf courses include Jimmy Clay, Roy Kizer, Morris Williams, Austin Country Club, Balcones Country Club, Barton Creek Fazio, Barton Creek Crenshaw, Lost Creek and Avery Ranch. Except for Avery Ranch, which uses native surface water from Brushy Creek for irrigation, all of the golf courses use reclaimed water or a mixture of groundwater and reclaimed water for irrigation. The golf course at Great Hills uses both reclaimed water and brackish groundwater from the Trinity Aquifer.

Samples collected at Avery Ranch Spring were used as the background samples for the purposes of this assessment. The mean conductivity at Avery Ranch Spring was 770 µS/cm (95% CI = 741.0-798.3 µS/cm) (Figure 24). The mean conductivity was significantly higher at Roy Kizer Spring (mean =

1120.8 µS/cm, 95% CI = 1016.8-1224.7 µS/cm) (t-test with unequal variance, $p < 0.0001$), which is slightly inside the range of conductance of groundwater that is considered "brackish". The most recent samples collected at Roy Kizer Spring have higher than normal conductivity readings. The range of conductivity is even higher (between 1000 µS/cm to 3000 µS/cm) at the Great Hills Golf Course resulting from the combined use of reclaimed water and Trinity Aquifer water.

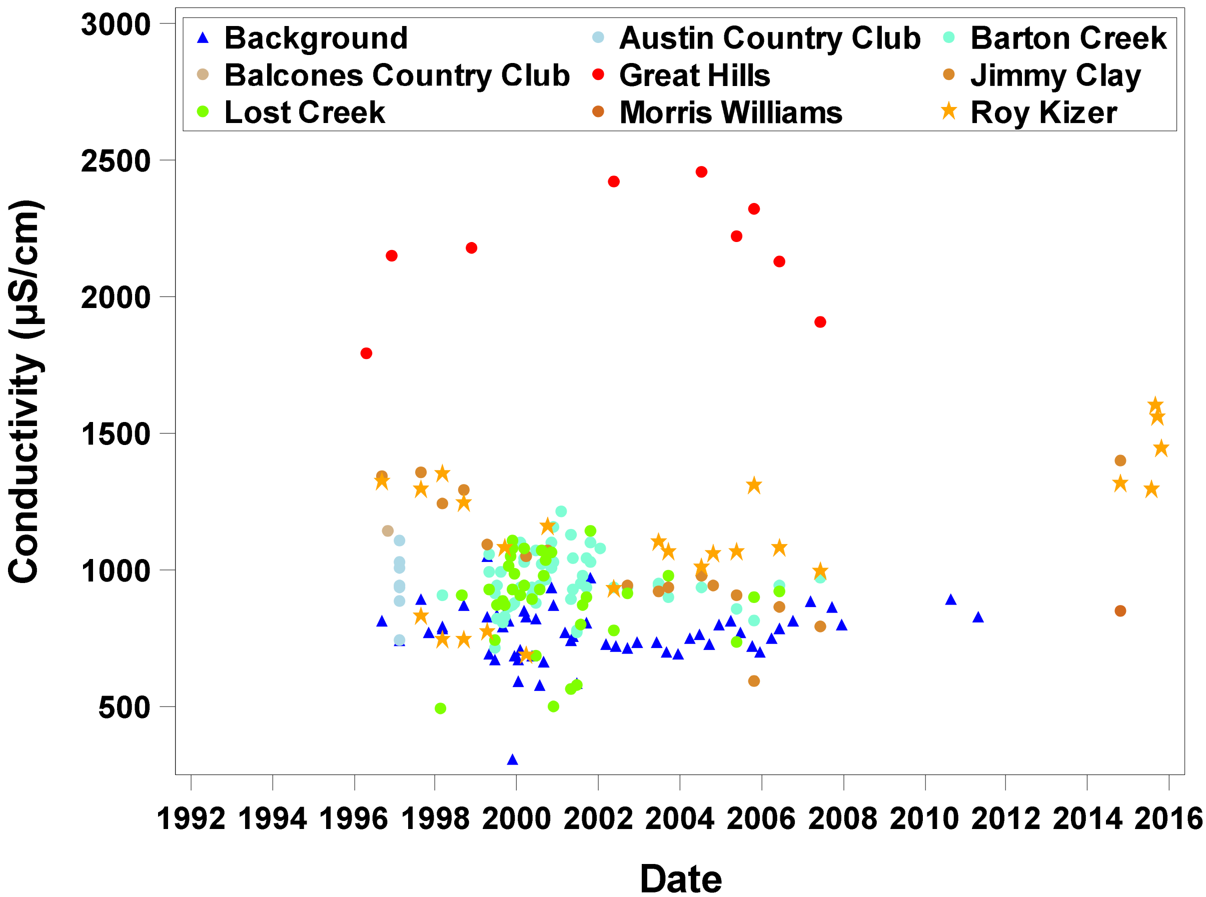

Figure 24: Conductivity at springs near Austin area golf courses (COA data). Most golf courses assessed that irrigate with reclaimed water generally have conductivity values above 770 µS/cm, the background condition for the purposes of this analysis. The high values at Great Hills results from the mixed use of reclaimed water and Trinity Aquifer groundwater.

Nitrate+nitrite nitrogen concentrations at golf course influenced springs in Austin range from 0.1 to 30 mg/L (Figure 25). Antecedent weather, irrigation rate, and spring discharge are all potential confounding factors that contribute to high variability in the data set. However, the mean nitrate+nitrite concentration at Avery Ranch Spring (background) was 2.26 mg/L (95% CI = 1.98 - 2.53 mg/L) which is significantly lower than the mean nitrate+nitrite concentration at Roy Kizer Spring (mean = 6.19 mg/L, 95% CI = 4.61 – 7.76 mg/L) (t-test with unequal variance, $p = 0.0001$). Roy Kizer Spring displays very high concentrations of nitrate in the most recent samples.

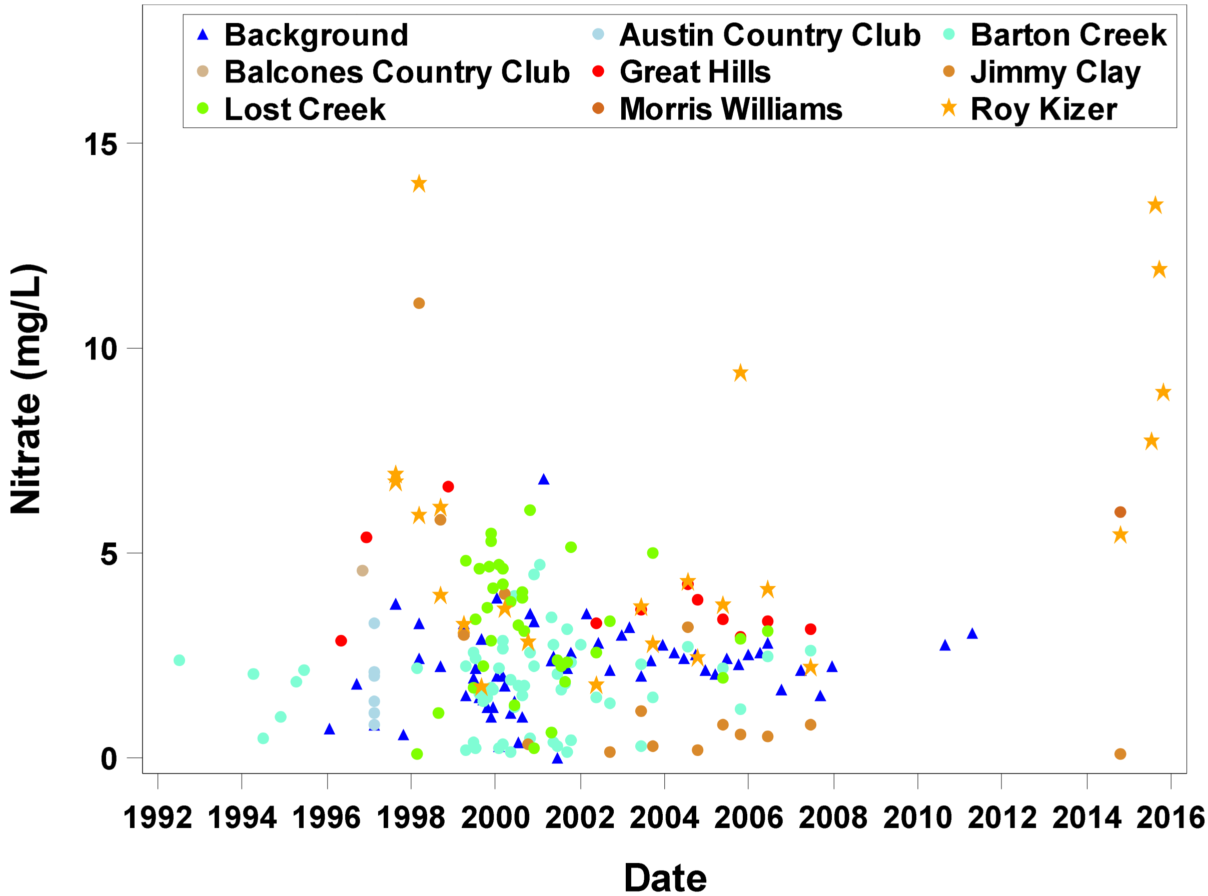

Figure 25: Nitrate+nitrite at springs near Austin area golf courses, showing that some of the highest concentrations were collected at Roy Kizer Spring during this study (2014-2015). Background concentrations for the purposes of this analysis, collected at Avery Ranch golf course (no reclaimed water irrigation), are generally below 5 mg/L.

A bivariate plot of conductivity and nitrate+nitrite nitrogen shows a positive linear relationship between increasing conductivity measurements and nitrate+nitrite nitrogen at the background golf course spring. This indicates that conductivity and nitrate+nitrite nitrogen may increase together (Figure 26). The ellipse shown in the bottom left corner of Figure 26 illustrates the zone of the 95% interval for background conductivity versus nitrate+nitrite. Data that is outside of the 95% ellipse may be considered to be different from background. There are a substantial amount of data points collected at Roy Kizer and Jimmy Clay golf courses that are outside this 95% ellipse and may be considered as different (in this case higher) than background conditions.

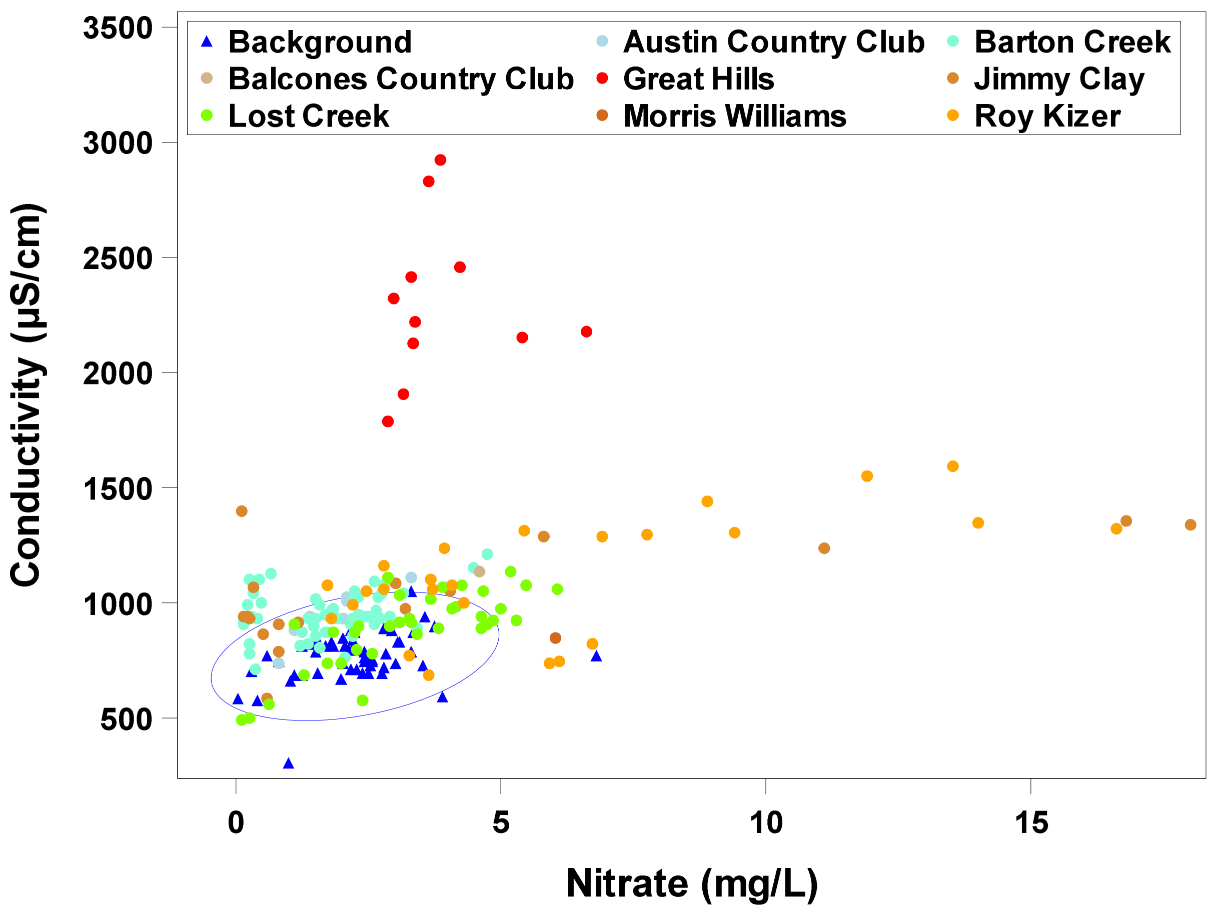

Figure 26: Conductivity versus nitrate in springs affected by golf courses. Background conditions for the purpose of this analysis are those at springs that do not include reclaimed water irrigation in the springshed, such as Avery Ranch. The ellipse shows the 95% interval for background conductivity versus nitrate. A majority of Roy Kizer, Jimmy Clay and Morris Williams values are outside the 95% background, suggesting that they are different from non-reclaim irrigated or upper gradient golf course springs.

<u>Antecedent Rainfall</u>

Rainfall data within the Tannehill watershed showed that all sample events were conducted under non-storm influenced conditions, although three of the four sampling events at Bartholomew Park followed fairly recently after rain events of more than 0.5 inches (Figure 27). Rainfall data within the Williamson watershed showed that the 15 October 2014 and 24 September 2015 sampling events followed rain events in which the total rainfall over the watershed was over 0.5 inches. There was little to no rain one month prior to the remaining sampling events at Clay/Kizer (Figure 28). The monthly irrigation volume at Clay/Kizer was highest for the 23 July 2015 and 27 August 2015 sampling events. Sample collection was attempted on 20 October 2015 for the Clay/Kizer sites, but Williamson Creek was not flowing at this time and no water column or benthic samples were collected.

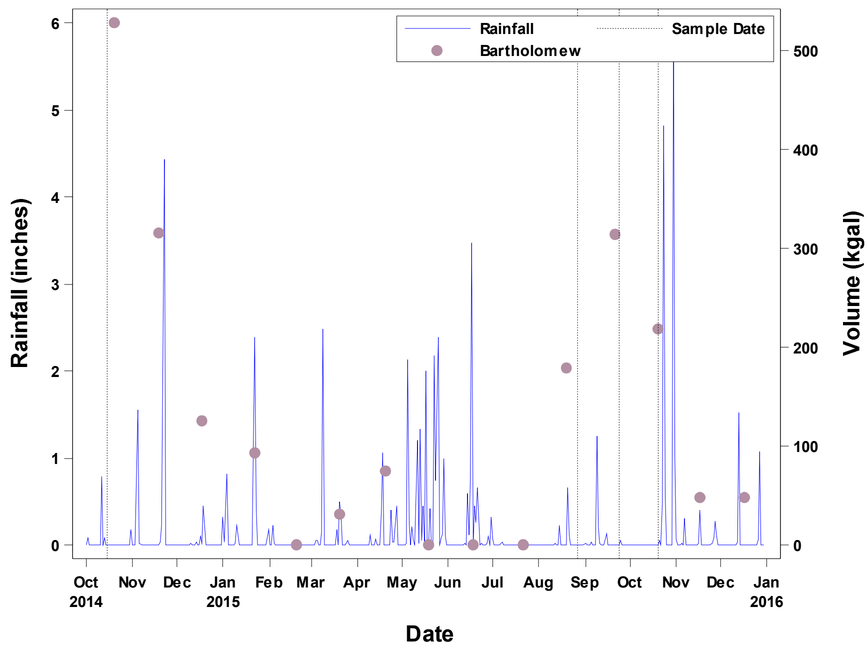

Figure 27: Rainfall (inches), Bartholomew Park irrigation volume (kgal) from October 2014 to December 2015. Dashed lines represent sampling events.

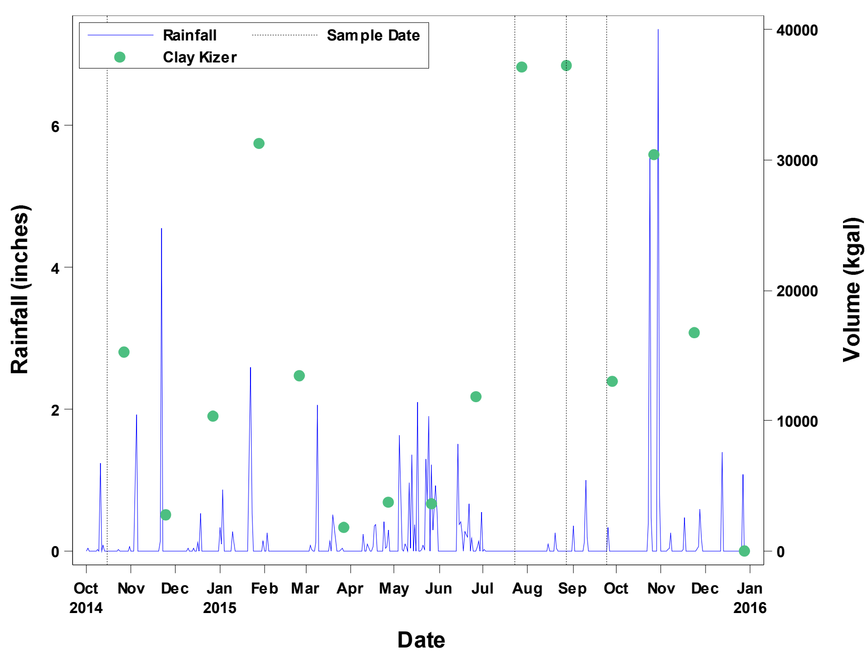

Figure 28: Rainfall (inches), Clay/Kizer irrigation volume (kgal) from October 2014 to December 2015. Dashed lines represent sampling events.

As Morris Williams Golf Course (Figure 29) also lies within the Tannehill watershed, rainfall and sampling patterns are similar to that of Bartholomew Park described previously. The monthly irrigation volume at Morris Williams was highest for the 27 August 2015 sampling event.

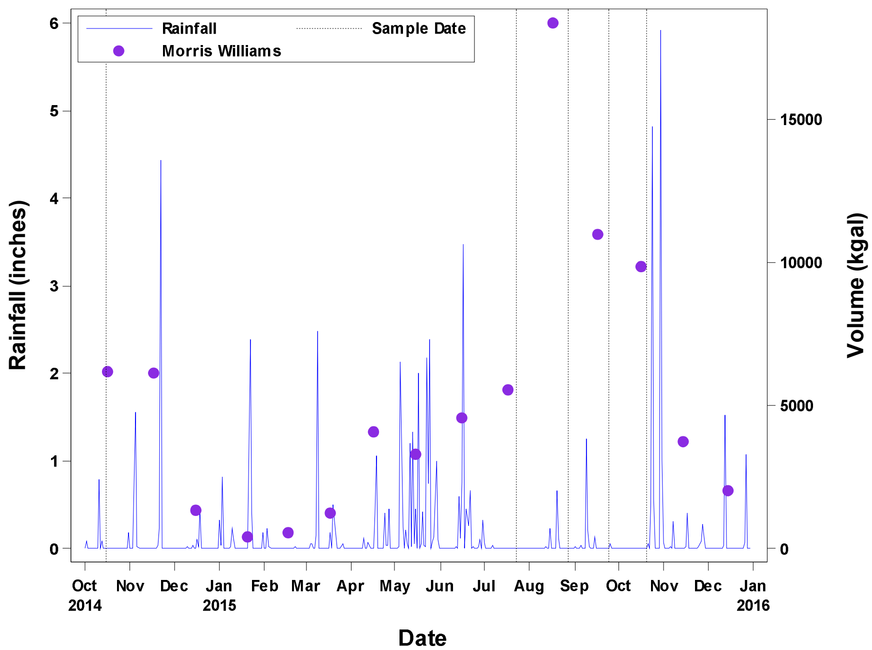

Figure 29: Rainfall (inches), Morris Williams irrigation volume (kgal) from October 2014 to December 2015. Dashed lines represent sampling events.

Nitrogen Isotopes

Lab analysis of the stable δ^{15}nitrogen and δ^{18} oxygen isotope ratios of nitrate collected during the October 25, 2014, sampling event revealed that all sites with sufficient nitrate for isotope analysis plotted in the biogenic range using common source fields by Kendall (1988). This suggests that the source of nitrogen was manure or wastewater (Figure 34). Similar isotopic comparisons have been used to identify potential wastewater effluent impacts to Austin area waterbodies by the United States Geological Survey (Mahler et al. 2011). There was no indication that the nitrogen in the study water bodies was originating from precipitation or fertilizer application. Both upstream and downstream sites on Waller Creek plotted in the biogenic range, possibly indicating leaking wastewater infrastructure upstream of the Hancock Golf Course.

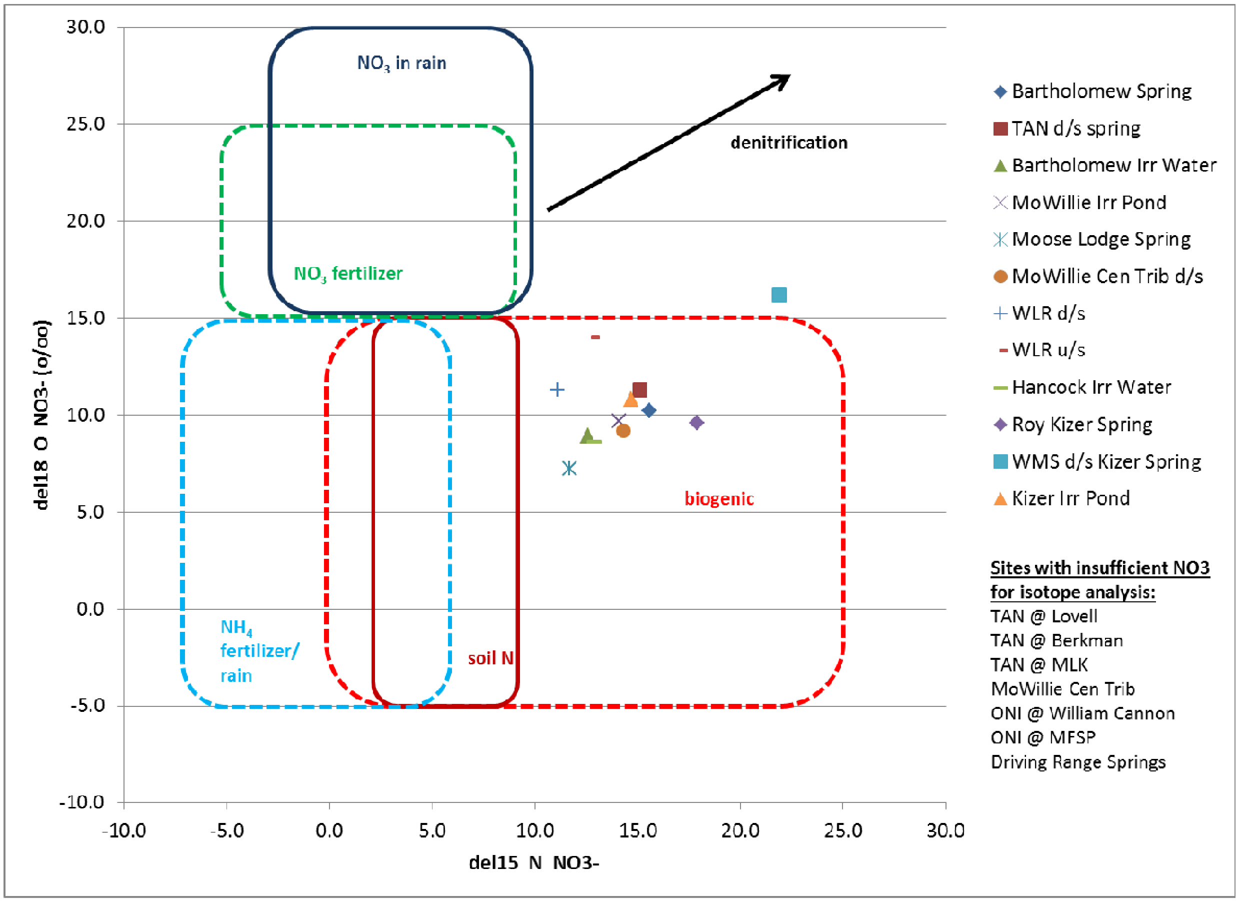

Figure 34: Nitrogen/Oxygen stable isotope ratio plot for study sites. Source boundaries adapted from Kendall (1998).

Conclusions

Using the conservation of mass, a conceptual model was established to determine whether there was a discernible impact from reclaimed water on adjacent surface water and groundwater resources. This model generated three hypotheses (see Methods section), which were tested against statistical intervals of data collected at each of three City of Austin facilities irrigating with reclaimed water. Furthermore, this conceptual model allowed for a more precise model, pHREEQc, which incorporated the interaction of geochemical processes into the model. The pHREEQc model provided predictions on the composition of downstream water given a certain mixture of upstream water and reclaimed water. This information was also used to verify the validity of the conceptual model and as an indication of the appropriateness of the hypothesis chosen. Finally, additional data was provided supporting the model and the conclusions presented below:

- Confidence intervals in surface water indicate that nitrate+nitrite and ions including sulfate, alkalinity, chloride, sodium, magnesium, potassium, and calcium are significantly higher in the downstream surface water samples at 2 of the 4 sites, Bartholomew and Roy Kizer (Figure 5, 9, and 11), but not significantly higher at Morris Williams mainstem and ambiguous for Morris Williams central tributary. Information from benthic nutrient ratios (discussed below) at Morris Williams central tributary removed this ambiguity.

- The benthic C:P confidence intervals exhibited a significant decrease from upstream to downstream sites indicating degradation downstream of reclaim water irrigation areas. While there was no significant difference in benthic C:N ratios from upstream to downstream, the probability of the benthic C:N ratios to be lower at downstream sites was high (0.89) and more samples would be necessary to validate indicate a significant decrease from upstream to downstream. In addition, benthic C:P and C:N ratios from only 2 of the 13 paired (upstream/downstream) samples were higher downstream than upstream (Figures 31 and 32). There was no significant difference in benthic chlorophyll *a* (mass per unit area) from upstream to downstream even though the nutrients for growth were more readily available to algae downstream of the irrigation. Thus, there was not a significant increase in biomass upstream to downstream observed in this study although confounding factors such as available sunlight (i.e., accounting for variable canopy cover at the study sites) were not evaluated in this analysis.

- The difference in benthic C:P and C:N ratios were most prominent in the mainstem of Tannehill Creek upstream and downstream of Morris Williams Golf Course. The differences in water column nutrients between the upstream and downstream locations at Morris Williams were the most ambiguous with this being the only paired location where there was not more nitrate+nitrite downstream of the irrigation.

- Piper plots of chemical facies indicate downstream waters generally trend from the upstream conditions toward the reclaimed water conditions indicating an influence of the reclaimed water on surface water resources (Figures 20, 21, and 23).

- The computer model, pHREEQc, estimated that about 40% of the downstream water at Bartholomew Park was from reclaimed water, validating the results from the confidence intervals at Bartholomew Park. The variability in the data at Roy Kizer could not reproduce a similarly precise estimate from pHREEQc of the reclaimed water contribution on the downstream section. Estimates of reclaimed water contribution on downstream sections of Morris Williams did not indicate an impact on the surface water, but benthic ratios show a clear uptake of the nutrients into the algal biomass.

- Samples from springs at the golf course study sites where reclaimed water is irrigated generally show higher conductivity than background conditions (Figures 24 and 26), consistent with previous local evaluations (Hiers and Herrington 2007). More specifically, conductivity collected at the spring adjacent to Roy Kizer is significantly higher than background conditions.

- Nitrate+nitrite concentrations at the spring impacted by Roy Kizer Golf Course are significantly higher than background concentrations, consistent with previous local evaluations (Hiers and Herrington 2007) and other U.S. Geological Survey studies (Pruitt et al. 1988, Katz et al. 2009). In fact, some of the highest nitrate+nitrite concentrations ever observed by the City of Austin in springs were collected at the Roy Kizer Golf Course. Of the 2,693 nitrate+nitrite samples collected from springs, the 10 highest values are all from Jimmy Clay and Roy Kizer, one of which was recently collected at Roy Kizer (Figures 22 and 25).

- Nitrogen and oxygen isotopes of nitrate for all sites with sufficient nitrate for analysis indicated that nitrogen is originating from biogenic (manure or wastewater) sources (Figure 34) during the October 2014 sampling event. Nitrogen in Waller Creek upstream of Hancock Golf Course also yielded a biogenic signature.

Based on these findings, the hypothesis that there is an impact (Hypothesis 2) to the receiving stream either on the surface water or the benthic algal stoichiometry that is likely attributable to the irrigation of reclaimed water is validated. Irrigation of reclaimed water appears to be inadvertently degrading the quality of adjacent surface water and groundwater resources based on the weight of evidence evaluated in this study.

Recommendations

1. Reclaimed water irrigation should not occur adjacent to waterways to avoid unintended adverse water quality impacts. A protective setback distance to avoid adverse impacts has not yet been quantitatively determined by the City of Austin Watershed Protection Department. The Critical Water Quality Zone (City of Austin Land Development Code Chapter 25-8-92), Erosion Hazard Zone (City of Austin Land Development Code Chapter 27-7-2, Drainage Criteria Manual Appendix E) and/or the City of Austin fully-developed floodplain boundaries should be considered as protective buffers in which no reclaimed water irrigation should occur, consistent with existing City of Austin policies and land development regulations to limit anthropogenic disturbance in these areas.

2. If irrigation of reclaimed water cannot be adjusted on a specific site so that it does not occur within the Critical Water Quality Zone and/or City of Austin fully-developed floodplain (e.g., potentially due to the width of these zones relative to the total size of a specific parcel), then site-specific characteristics (e.g., soils, geology, topography, vegetation) should be evaluated on a case-by-case basis to determine appropriate protective setbacks.

3. If it is determined that current irrigation of reclaimed water on public parks adjacent to waterways is unavoidable, then measures should be implemented over time to minimize adverse impacts to surface water. Mitigation measures may include, but are not limited to, revised riparian vegetation management practices that maximize nutrient uptake, sprinkler head adjustments, and additional monitoring to identify potential adjustments to irrigation rates or schedule while meeting turf grass needs. That additional monitoring could also improve the statistical intervals developed in this report.

4. Additional sampling as described in the Methods section of this report is recommended to increase the resolution of benthic C:N ratios upstream and downstream of irrigation sites to more conclusively determine if impacts are present for this parameter.

5. Benthic chlorophyll *a* concentrations (mass per unit area) were too variable to discern an upstream to downstream statistical pattern. Additional explanatory variables like canopy cover need to be accounted for when using benthic chlorophyll *a* as a measure of degradation in similar scenarios.

Discussion

Reclaimed water is a priority demand-side water conservation strategy for the City of Austin, as recognized in the Austin Water Resource Planning Task Force Report to City Council (July 2014, austintexas.gov/page/austin-water-resource-planning-task-force). Reclaimed water use not only reduces the discharge of treated effluent to the Colorado River, but also reduces the withdrawal of high quality raw water from Lake Austin and Lake Travis. The Austin Water Utility has 74 active metered reclaimed water customers, four bulk fill stations, and more than 50 miles of reclaimed water distribution pipelines already installed. Reuse of City of Austin reclaimed water constitutes approximately 3% of total wastewater volume treated. For site plan applications submitted on or after May 1, 2015, the City of Austin mandates connection of new commercial development to the reclaimed water distribution system if the development is within 250 ft of a reclaimed water main. Thus, applying restrictions on current or future reclaimed water irrigation should be carefully considered.

This report proposes restrictions on reclaimed water irrigation within the floodplain, CWQZ or EHZ (see Recommendations). Planning staff within the City of Austin Watershed Protection Department conducted four geographic information system (GIS) analyses of the potential implications of the Recommendations of this report on existing, planned, and new potential reclaimed water customers. These analyses utilized Travis County Appraisal District (TCAD) parcel boundaries within the actual Austin Water Utility water service area (water pressure zone). Parcel boundaries were intersected with City of Austin fully-developed floodplain (floodplain), Critical Water Quality Zone (CWQZ) and Erosion Hazard Zone (EHZ) boundaries.

Scenario 1, all parcels within Austin Water Utility actual water service area

This scenario assessed the percent area of 207,433 individual TCAD parcels in the actual Austin Water water service area within the floodplain, CWQZ and EHZ on an individual parcel basis. Of the 207,433 parcels assessed, there were 175,501 parcels (84.6% of total) with no area either within the floodplain, CWQZ, or EHZ. Approximately 99.19% of parcels have less than 3% of the area within the parcel boundaries falling within the floodplain, CWQZ or EHZ. Less than 0.02% of parcels are estimated to have 75% or more of the total parcel area falling within the floodplain, CWQZ or EHZ. Thus, on a citywide basis the restrictions on reclaimed water irrigation proposed in the Recommendations section of this report would have a minimal impact future reclaimed water use (Table 5).

Table 5. Analysis of the most restrictive (maximum) impact of limitation on reclaimed water irrigation on all parcels within the Austin Water Utility actual water service area.

Maximum Percent of Parcel Affected (Bin)	# of Parcels within the Bin	% of Total Number of Parcels within the Bin
0	175,501	84.61
less than 1%	28,500	13.74
1%-2%	1,205	0.58
2%-3%	539	0.26
3-4%	377	0.18
4-5%	243	0.12
5-6%	170	0.08
6-7%	128	0.06
7-8%	89	0.04
8-9%	96	0.05
9-10%	73	0.04
10-25%	343	0.17
25-50%	100	0.05
50-75%	26	0.01
75-100%	43	0.02

Scenario 2, potential new reclaimed water customer impact

This scenario assessed the potential impact of the restrictions on reclaimed water irrigation proposed in the Recommendations section of this report on potential new reclaimed water customers as identified by Austin Water in February 2015. The maximum pervious area of the 31 TCAD parcels within the floodplain, CWQZ or EHZ was assessed. Two of the 31 potential new customer parcels had no pervious area (as defined by City of Austin Environmental Criteria Manual) within the parcel boundaries. The majority (96.7%) of identified potential new customers had less than 2% of their pervious areas falling within the floodplain, CWQZ or EHZ. The maximum impact was 5.4% of the pervious area, occurring on one parcel (Table 6).

Table 6. Analysis of most restrictive (maximum) impact of limitation on reclaimed water irrigation on the pervious area of parcels identified as potential new reclaimed water customers (as of February 2015).

Maximum Percent of Pervious Area Within Parcel Affected (Bin)	# of Parcels within Bin	% of Total # of Parcels
No Pervious Area	2	6.45
No impact	18	58.06
Less than 1%	8	25.81
1-2%	2	6.45
5-6%	1	3.23

<u>Scenario 3, potential impact to existing reclaimed water customers</u>
This scenario intersected TCAD parcel boundaries for 45 existing Austin Water reclaimed water customers (as identified in February 2015) with the floodplain, CWQZ and EHZ boundaries. The majority of existing reclaimed water customer parcels (64.4%) had no pervious area within the floodplain, CWQZ or EHZ. Only 11.1% of existing customer parcels had 50% of their total pervious area within the floodplain, CWQZ or EHZ.

Table 7. Analysis of most restrictive (maximum) impact of limitation on reclaimed water irrigation on the pervious area of parcels for existing reclaimed water customers (as of February 2015).

Maximum Percent of Pervious Area with Parcel Affected (Bin)	# of Parcels within Bin	% of Total # of Parcels
No impact	29	64.44
Less than 10%	2	4.44
10-20%	4	8.89
20-30%	1	2.22
30-40%	2	4.44
40-50%	2	4.44
50-60%	1	2.22
60-70%	0	0.00
70-80%	2	4.44
80-90%	0	0.00
90-100%	2	4.44

<u>Scenario 4, parcels within 100 ft of a current or proposed reclaimed water main</u>
This scenario identified parcels within the Austin Water actual water service area located within 100 ft of a current or proposed reclaimed water distribution main. The pervious (irrigable) area for these 6,940 parcels also falling within the floodplain, CWQZ or EHZ was assessed. The majority of parcels (81%) within 100 ft of an existing or reclaimed water distribution main had all of their pervious area falling within the floodplain, CWQZ or EHZ. Approximately 6.2% of parcels had no pervious area outside of the floodplain, CWQZ or EHZ. Approximately 10.6% of parcels within 100 ft of an existing or planned

reclaimed water distribution main would not be able to irrigate reclaimed water on 50% or more of their pervious area as a result of restrictions proposed in the Recommendations section (Table 8).

Table 8. Analysis of most restrictive (maximum) impact of limitation on reclaimed water irrigation on the pervious area of parcels within 100 ft of an existing or planned reclaimed water distribution main.

Maximum % of Pervious Area within Parcel Affected (Bin)	# of Parcels within Bin	% of Total # of Parcels
0%	5624	81.04
less than 1%	48	0.69
1-10%	129	1.86
10-20%	118	1.70
20-30%	104	1.50
30-40%	97	1.40
40-50%	80	1.15
50-60%	80	1.15
60-70%	74	1.07
70-80%	78	1.12
80-90%	73	1.05
90-100%	435	6.27

Acknowledgements

This initial sampling event was completed with the assistance of multiple City of Austin Parks and Recreation Department staff that facilitated access to the park and golf course study locations. Additionally, Dan Pedersen with Austin Water provided background information on the use of reclaimed water at these locations, and provided reclaimed water sampling information. The City of Austin Watershed Protection Department expresses sincere appreciation to these individuals for their valuable assistance with this project.

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Appendix A Paired Differences

Table A.1: Confidence Intervals of the Mean Paired Differences in Concentrations (mg/L, unless otherwise noted) between Downstream and Upstream Samples in Bartholomew Park

Parameter Name	Bayes LCI	Bayes Median	Bayes UCI
DISSOLVED OXYGEN	-5.6	-1.6	2.0
pH (standard units)	-0.35	-0.10	0.15
Ammonia	-0.14	0.02	0.18
Nitrate	1.04	1.76	2.45
TKN	-0.19	0.11	0.39
Total Nitrogen	1.20	1.84	2.48
Orthophosphorus	-0.032	0.009	0.046
Phosphorus	-0.023	0.023	0.069
Alkalinity	96.2	106.9	117.8
Chloride	16.5	41.0	63.5
Sodium	12.9	29.9	45.7
Magnesium	3.0	5.0	6.8
Calcium	32.4	55.0	74.2
Potassium	0.3	1.2	2.1
Sulfate	5.8	30.5	57.5
Fluoride	-0.04	0.00	0.04
Strontium	0.09	0.19	0.27

Table A.2: Confidence Intervals of the Mean Paired Differences in Concentrations (mg/L, unless otherwise noted) between Downstream and Upstream Samples in Morris Williams (main stem)

Parameter Name	Bayes LCI	Bayes Median	Bayes UCI
DISSOLVED OXYGEN	-4.9	-1.4	1.9
pH (standard units)	-0.34	-0.13	0.09
Ammonia	-0.06	0.08	0.25
Nitrate	-1.02	-0.39	0.27
TKN	0.11	0.39	0.66
Total Nitrogen	0.32	0.95	1.58
Orthophosphorus	-0.028	0.010	0.043
Phosphorus	-0.017	0.025	0.067
Alkalinity	-68.7	-59.0	-49.3
Chloride	-9.0	11.1	33.8
Sodium	-7.3	7.0	22.7
Magnesium	-1.5	0.2	1.9
Calcium	-43.8	-26.3	-5.3
Potassium	-0.2	0.6	1.4
Sulfate	-14.4	11.5	36.3
Fluoride	-0.05	-0.01	0.03
Strontium	-0.16	-0.09	-0.01

Table A.3: Confidence Intervals of the Mean Paired Differences in Concentrations (mg/L, unless otherwise noted) between Downstream and Upstream Samples in Morris Williams (central tributary)

Parameter Name	Bayes LCI	Bayes Median	Bayes UCI
DISSOLVED OXYGEN	-2.0	1.6	5.1
pH (standard units)	0.47	0.67	0.86
Ammonia	-0.19	-0.02	0.12
Nitrate	0.16	0.79	1.45
TKN	-0.21	0.07	0.34
Total Nitrogen	-0.50	0.80	2.10
Orthophosphorus	-0.008	0.026	0.069
Phosphorus	-0.004	0.035	0.084
Alkalinity	1.6	11.2	21.0
Chloride	-1.6	18.6	39.2
Sodium	-3.9	10.2	25.1
Magnesium	-1.4	0.2	2.0
Calcium	-1.3	17.0	35.0
Potassium	-1.0	-0.2	0.7
Sulfate	0.7	24.2	47.1
Fluoride	-0.02	0.02	0.05
Strontium	-0.02	0.05	0.13

Table A.4: Confidence Intervals of the Mean Paired Differences in Concentrations (mg/L, unless otherwise noted) between Downstream and Upstream Samples in Roy Kizer

Parameter Name	Bayes LCI	Bayes Median	Bayes UCI
DISSOLVED OXYGEN	-4.8	-1.3	2.1
pH (standard units)	-0.64	-0.43	-0.20
Ammonia	-0.17	0.01	0.18
Nitrate	2.33	3.20	4.00
TKN	0.00	0.31	0.65
Total Nitrogen	-0.78	3.62	8.02
Orthophosphorus	-0.044	0.005	0.043
Phosphorus	-0.053	0.011	0.056
Alkalinity	28.0	40.0	52.2
Chloride	18.5	48.9	74.4
Sodium	15.9	37.2	55.3
Magnesium	3.3	5.6	7.7
Calcium	11.6	36.3	58.8
Potassium	2.7	3.9	5.0
Sulfate	11.0	40.0	72.6
Fluoride	-0.01	0.03	0.08
Strontium	-0.09	0.00	0.10

Appendix B Confidence Intervals of the Mean

Table B.1: Confidence Intervals of the Mean in Concentrations (mg/L) at Bartholomew Park

Parameter Name	Bayes LCI	Bayes Median	Bayes UCI
Upstream			
Orthophosphorus	<DL	<DL	<DL
Phosphorus	<DL	0.02	0.14
Nitrate	<DL	0.09	3.56
TKN	0.056	0.53	0.99
Alkalinity	69.64	102.4	134.6
Chloride	<DL	16.02	34.64
Sodium	<DL	12.56	27.11
Magnesium	<DL	3.56	7.99
Calcium	25.50	44.46	63.56
Potassium	1.50	2.426	3.36
Sulfate	<DL	16.44	33.28
Fluoride	0.14	0.37	0.59
Downstream			
Orthophosphorus	<DL	.01	.02
Phosphorus	<DL	0.04	0.26
Nitrate	<DL	1.32	3.65
TKN	0.15	0.51	0.87
Alkalinity	195.4	224.9	251.7
Chloride	52.70	63.11	73.18
Sodium	38.29	48.29	58.09
Magnesium	6.05	8.98	11.86
Calcium	86.22	101.00	115.00
Potassium	3.38	3.95	4.51
Sulfate	46.42	56.18	65.61
Fluoride	0.21	0.36	0.52
Reclaimed Water			
Orthophosphorus	4.22	4.56	4.90
Phosphorus	4.53	4.69	4.84
Nitrate	25.6	28.6	31.5
TKN	0.3	0.7	1.2
Alkalinity	<DL	27.7	62.2
Chloride	107.5	120.5	132.7
Sodium	114.9	127.6	139.4
Magnesium	30.5	34.1	37.6
Calcium	32.8	50.4	67.9
Potassium	14.1	14.8	15.5
Sulfate	173.0	185.1	196.4
Fluoride	1.9	2.1	2.3

Table B.2: Confidence Intervals of the Mean in Concentrations (mg/L) at Morris Williams (main stem)

Parameter Name	Bayes LCI	Bayes Median	Bayes UCI
Upstream			
Orthophosphorus	<DL	<DL	<DL
Phosphorus	<DL	<DL	0.03
Nitrate	<DL	0.71	2.87
TKN	<DL	0.26	0.62
Alkalinity	217.8	245.6	271.1
Chloride	25.59	34.99	44.56
Sodium	16.09	25.22	34.52
Magnesium	3.11	5.80	8.51
Calcium	97.00	110.70	123.50
Potassium	1.30	1.83	2.36
Sulfate	29.08	38.15	46.98
Fluoride	0.21	0.34	0.48
Downstream			
Orthophosphorus	<DL	0.01	0.03
Phosphorus	<DL	0.05	0.17
Nitrate	<DL	0.34	2.75
TKN	0.251	0.60	0.96
Alkalinity	138.40	161.80	184.10
Chloride	25.22	38.41	51.37
Sodium	16.71	27.10	37.42
Magnesium	2.35	5.40	8.50
Calcium	61.38	75.18	88.54
Potassium	1.742	2.392	3.055
Sulfate	26.26	38.19	50.01
Fluoride	0.15	0.31	0.47
Reclaimed Water			
Orthophosphorus	4.22	4.56	4.90
Phosphorus	4.53	4.69	4.84
Nitrate	25.6	28.6	31.5
TKN	0.3	0.7	1.2
Alkalinity	<DL	27.6	55.8
Chloride	107.5	120.5	132.7
Sodium	114.9	127.6	139.4
Magnesium	30.5	34.1	37.6
Calcium	32.8	50.4	67.9
Potassium	14.1	14.8	15.5
Sulfate	173.0	185.1	196.4
Fluoride	1.9	2.1	2.3

Table B.3: Confidence Intervals of the Mean in Concentrations (mg/L) at Morris Williams (central tributary)

Parameter Name	Bayes LCI	Bayes Median	Bayes UCI
Upstream			
Orthophosphorus	<DL	<DL	<DL
Phosphorus	<DL	0.02	0.04
Nitrate	4.55	5.73	6.95
TKN	7.16	7.32	7.48
Alkalinity	<DL	1.07	2.31
Chloride	0.17	0.30	0.44
Sodium	129	216	291
Magnesium	6.13	30.44	52.21
Calcium	11.05	25.31	38.80
Potassium	2.68	4.98	7.27
Sulfate	38.29	96.77	145.30
Fluoride	1.50	2.45	3.39
Downstream			
Orthophosphorus	<DL	0.05	0.15
Phosphorus	<DL	0.07	0.19
Nitrate	0.53	1.76	3.00
TKN	0.19	0.32	0.45
Alkalinity	135	223	297
Chloride	18.82	43.03	65.90
Sodium	17.57	32.22	46.09
Magnesium	2.83	5.08	7.34
Calcium	49.63	111.10	160.70
Potassium	1.34	2.28	3.19
Sulfate	16.99	48.96	79.44
Fluoride	0.34	0.39	0.45
Reclaimed Water			
Orthophosphorus	4.22	4.56	4.90
Phosphorus	4.53	4.69	4.84
Nitrate	25.6	28.6	31.5
TKN	0.3	0.7	1.2
Alkalinity	<DL	27.6	55.8
Chloride	107.5	120.5	132.7
Sodium	114.9	127.6	139.4
Magnesium	30.5	34.1	37.6
Calcium	32.8	50.4	67.9
Potassium	14.1	14.8	15.5
Sulfate	173.0	185.1	196.4
Fluoride	1.9	2.1	2.3

Table B.4: Confidence Intervals of the Mean in Concentrations (mg/L) at Roy Kizer

Parameter Name	Bayes LCI	Bayes Median	Bayes UCI
Upstream			
Orthophosphorus	<DL	0.01	0.02
Phosphorus	<DL	0.02	0.04
Nitrate	<DL	1.11	5.45
TKN	<DL	0.19	0.77
Alkalinity	161.7	207.1	247.8
Chloride	5.36	39.09	75.13
Sodium	1.54	24.39	49.62
Magnesium	4.63	8.59	12.68
Calcium	64.91	94.38	120.20
Potassium	0.38	1.96	3.67
Sulfate	15.05	49.23	79.48
Fluoride	0.11	0.31	0.53
Downstream			
Orthophosphorus	<DL	<DL	0.03
Phosphorus	<DL	0.02	0.05
Nitrate	<DL	3.50	7.13
TKN	0.01	0.46	0.93
Alkalinity	198.8	238.8	274.5
Chloride	46.44	78.99	107.20
Sodium	33.82	54.55	73.82
Magnesium	9.43	12.81	16.32
Calcium	93.12	121.30	143.70
Potassium	4.17	5.62	7.07
Sulfate	46.77	80.44	108.50
Fluoride	0.16	0.34	0.53
Reclaimed Water			
Orthophosphorus	0.26	1.59	2.92
Phosphorus	1.32	1.81	2.29
Nitrate	9.23	13.26	16.73
TKN	0.79	1.32	1.77
Alkalinity	63.2	102.1	138.3
Chloride	59.23	97.33	124.90
Sodium	60.82	85.62	104.40
Magnesium	20.84	24.59	27.95
Calcium	19.40	42.66	67.07
Potassium	13.72	15.20	16.61
Sulfate	32.15	61.11	87.58
Fluoride	0.98	1.17	1.35

Appendix C

Benthic algae carbon to phosphorus (C:P) ratios, carbon to nitrogen (C:N) ratios, and benthic algae chlorophyll *a* collected upstream and downstream of each reclaim irrigation site.

Date	Site	Benthic C:P Ratio		Benthic C:N Ratio		Benthic chlorophyll *a* (mg/m^2)	
		Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
15-OCT-14	Bartholomew	11.13	10.45	2.15	1.59	35.81	57.32
	Clay/Kizer: Onion	17.66	6.08	2.56	2.17	14.30	8.40
	Clay/Kizer: Williamson	26.27	9.78	8.30	1.91	9.30	41.90
	Hancock	7.95	9.79	1.35	1.80	26.47	65.82
	Morris Williams	15.34	7.76	2.29	1.87	80.40	90.02
23-JUL-15	Clay/Kizer: Williamson	14.18	11.48	1.49	0.85	136.31	104.46
	Morris Williams	23.08	11.93	1.68	1.66	25.34	54.78
27-AUG-15	Bartholomew	10.11	12.02	1.79	1.53	72.61	105.02
	Clay/Kizer: Williamson	14.85	16.21	2.48	1.73	57.04	47.98
	Morris Williams	21.11	16.23	2.10	1.79	167.02	98.37
24-SEP-15	Bartholomew	17.50	10.91	1.40	1.85	31.99	78.70
	Clay/Kizer: Williamson	15.23	13.46	0.50	0.65	109.41	112.95
	Morris Williams	19.39	4.65	0.73	0.46	93.70	54.78
20-OCT-15	Bartholomew	18.18	8.15	1.81	1.57	30.29	223.64
	Morris Williams	21.77	11.99	1.96	1.77	57.75	52.94

Appendix D

Differences between total nitrogen in the water column, benthic C:P, benthic C:N, and benthic chlorophyll *a* for each sampling event were analyzed (Figures D1-D4). C:P ratios and C:N ratios are thought to be lower in streams where nutrients are available for uptake at high concentrations, which can result in low water column concentrations of nutrients because the periphyton has acquired the nutrients.

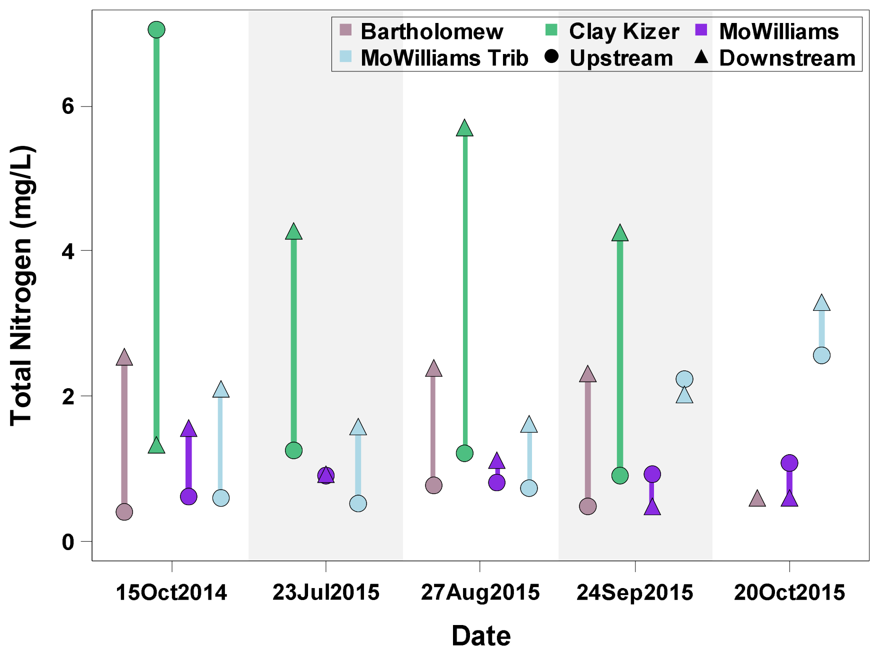

Figure D.1: Upstream and downstream total nitrogen (mg/L) collected from Bartholomew Park, Roy Kizer, and Morris Williams surface water beginning in October 2014 to December 2015.

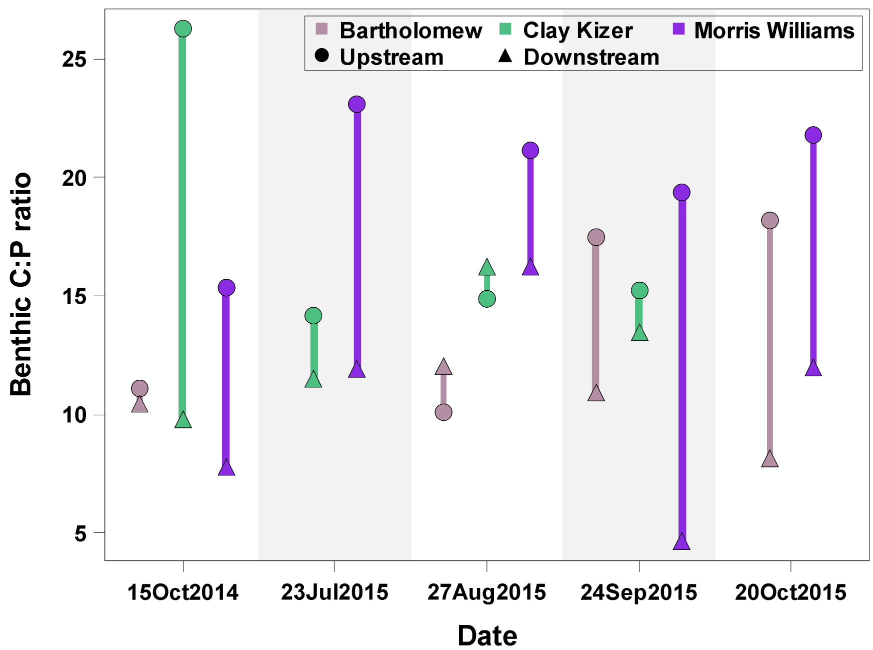

Figure D.2: Upstream and downstream benthic C:P collected from Bartholomew Park, Roy Kizer, and Morris Williams beginning in October 2014 to December 2015.

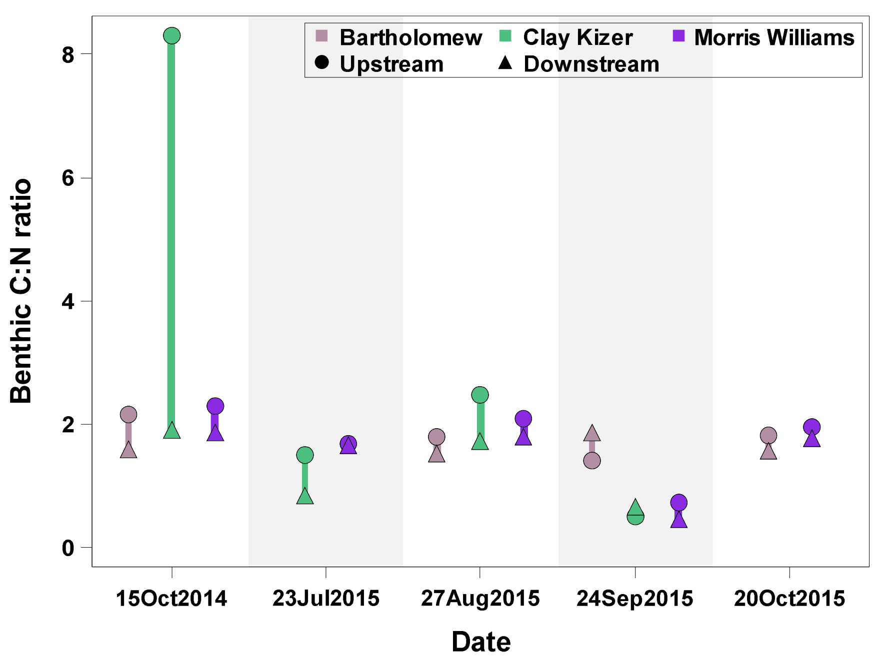

Figure D.3: Upstream and downstream benthic C:N collected from Bartholomew Park, Roy Kizer, and Morris Williams beginning in October 2014 to December 2015.

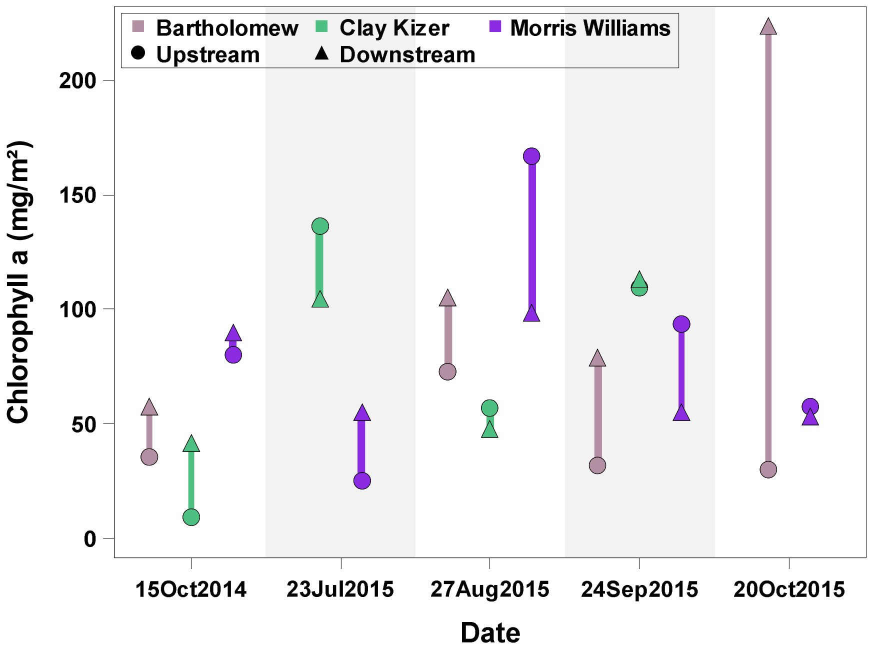

Figure D.4: Upstream and downstream benthic chlorophyll *a* (mg/m^2) collected from Bartholomew Park, Roy Kizer, and Morris Williams beginning in October 2014 to December 2015.